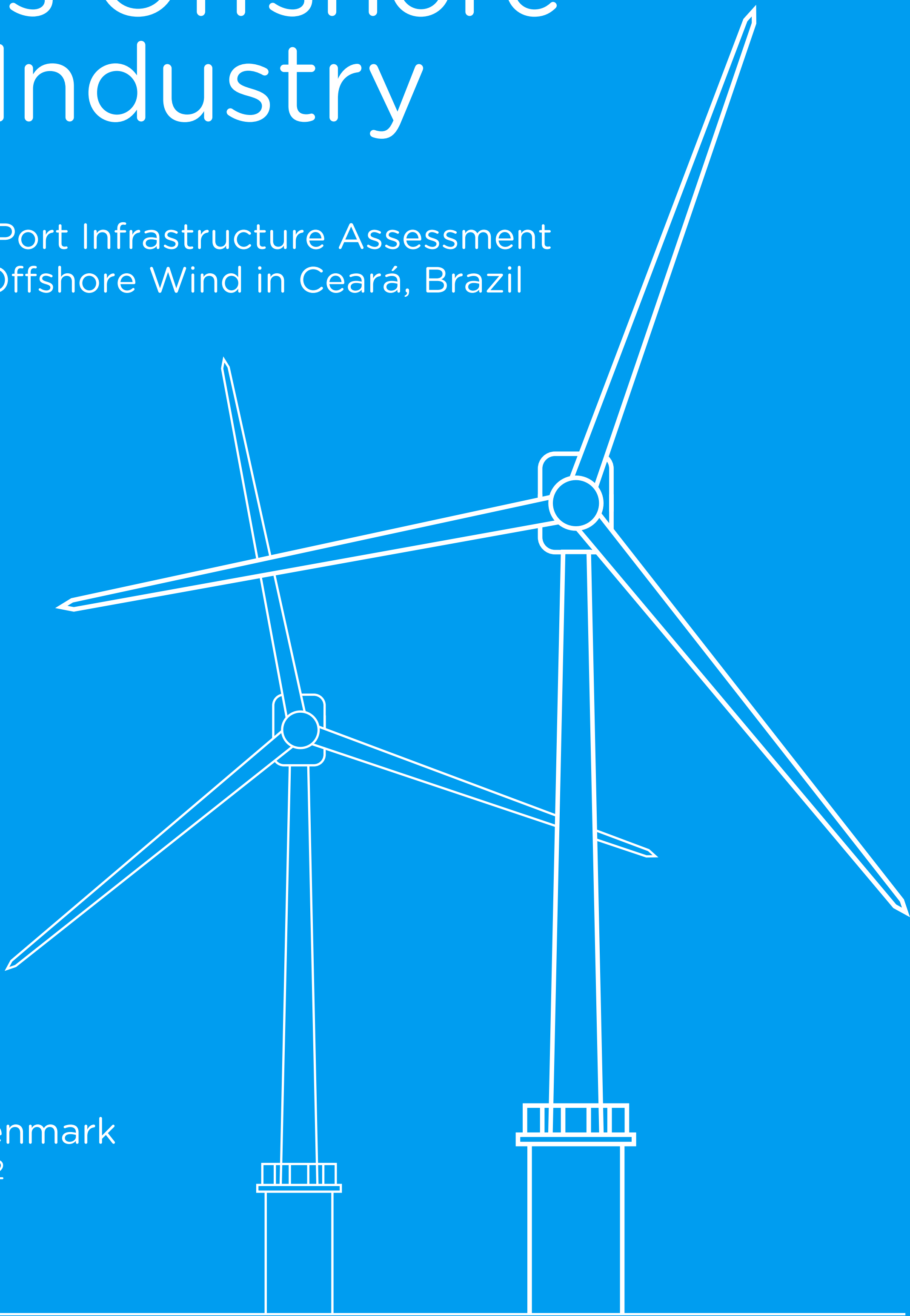
Paving the Way for Ceará's Offshore Wind Industry

Supply Chain and Port Infrastructure Assessment for Bottom-fixed Offshore Wind in Ceará, Brazil



Energy Cluster Denmark

Published October 2022

RAMBOLL

PAVING THE WAY FOR CEARÁ'S OFFSHORE WIND INDUSTRY
SUPPLY CHAIN AND PORT INFRASTRUCTURE ASSESSMENT FOR BOTTOM-FIXED OFFSHORE WIND IN CEARÁ, BRAZIL

Project name	Supply Chain and Port Infrastructure Assessment for Bottom-Fixed Offshore Wind in Ceará, Brazil
Project no.	352003011
Recipient	Energy Cluster Denmark
Document type	Report
Version	2
Date	July 29, 2022
Prepared by	Pierre Amiot, Marcelo Machado Brizzotti, Gabriel Freitas, Cleiton Luiz Foster Jardewski, Anna Hillstrom Meding, Maximilian Foy
Checked by	Hugo Diogo Lamas, Simon Tiedemann, Nils Kirchhoff, Hinnerk Maxl, David Ryan VanLuvanee, Sharareh Jalili, Elson Martins, Anna Hillstrom Meding
Approved by	Lisa Keaton

DISCLAIMER

COPYRIGHT @RAMBOLL 2022

ACKNOWLEDGEMENTS

This report is published on behalf of Energy Cluster Denmark and as part of the innovation project, Wind Energy Innovation Collaboration - Brazil and Denmark (INNOWIND Brazil & Denmark).

The INNOWIND project's purpose is to strengthen the Brazilian wind industry and supply chain through positioning Danish innovative competencies and know-how within wind energy in Brazil, as well as by supporting the development of an innovative energy cluster in the state of Ceará, Brazil. INNOWIND will spur export of Danish wind technology and services to Brazil and increase Denmark's government-to-government cooperation through public-private partnerships.

This report is supported by the following organizations:

Additionally, Ramboll would like to thank the following stakeholders for their perspectives, insights and engagement:

As well as thank the following stakeholder for their financial support:

This report was authored by Ramboll:

FOREWORD

energy CLUSTER DENMARK

Copenhagen, July 2022

The acceleration of the global green transition towards a sustainable economy is crucial in the fight to mitigate climate change. Climate change is amongst the greatest and most imminent global challenges we face. Denmark and Brazil are both green transition frontrunners in various technical areas and can therefore benefit greatly from strong bilateral cooperation on innovations furthering the energy transition.

Brazil has great ambitions when it comes to offshore wind development! Denmark has more than 30 years proven track record in offshore wind development, starting with Vindeby - the world's first offshore wind farm back in 1991. This first wind farm blossomed into an experienced and innovative Danish supply chain, which supported turning offshore wind into a competitive renewable energy source globally.

The state of Ceará is among the leading states producing renewable energy in Brazil. Offshore wind development is expected to take off in Brazil in the coming years with several projects anticipated to be built from Ceará's coastline. The Government of the State of Ceará, represented by Secretariat of Economic Development and Labor (SEDET), has great ambitions in strengthening their position as one of the leading renewable energy hubs and technology centres in Brazil.

Energy Cluster Denmark (ECD) was awarded several times Gold Cluster Management Excellence by the European Commission through the European Cluster Excellence Initiative (ECEI). ECD is ready to support Brazil and the State of Ceará on this development through innovative Danish competencies and know-how.

This report is part of the INNOWIND Brazil & Denmark - Wind Energy Innovation Collaboration and one of the first steps in clarifying some of the challenges and opportunities in offshore wind development in Brazil, with a greater focus on the state of Ceará, and thereby creating a basis for Danish and Brazilian collaboration.

I would like to take this opportunity to thank all partners of the INNOWIND project, particularly the Government State of Ceará, the Secretariat of Economic Development and Labor (SEDET) in Ceará, and the Ministry of Foreign Affairs in Denmark represented by the Royal Danish Consulate General - São Paulo, for providing qualitative inputs to this report, participating in valuable discussions and the reciprocal trust built through knowledge sharing and openness: the basic values to enable innovation and collaboration. My sincere gratitude also to the consultancy company, Ramboll, for their tireless efforts to realize and complete this report. In addition, Vestas Wind Systems for their support and commitment in making this report useful and valuable for the industry and pushing boundaries for innovation and business development collaboration among Danish and Brazilian enterprises. These words also echo to all industry contributors and associations that provided inputs throughout the process! Finally, the Danish Energy Agency for their interest and financial funding of the report and the activities in the INNOWIND project.

I hope this report can contribute to bringing forward new ideas and innovative collaborations that will enable offshore wind development both in Brazil and in the state of Ceará for the benefit of the Brazilian and Danish supply chains. I wish you a joyful reading! Please stay tuned for upcoming INNOWIND activities!

Glenda Napier
CEO, Energy Cluster Denmark

EXECUTIVE SUMMARY

In the last months, the Brazilian offshore wind market became one of the most active emerging markets in the globe. Spurred on by the January 2022 publication of Decree 10.946, which set the basis for establishing offshore energy projects, a total of 50 offshore wind projects spread across six Brazilian states have filed applications to begin the environmental licensing process with the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) [1]. With an estimated 480-700 GW in technical offshore wind potential for bottom-fixed offshore sites [1, 2], Brazil is seen by many players as a market "too big to ignore."

While submissions to IBAMA are a strong indicator of market appetite, there is still much progress to be made before the first turbine is installed. To successfully navigate this new industry, collaboration and partnerships with existing offshore wind markets will be powerful tools to help realize Brazil's huge potential.

The INNOWIND project is a wind energy innovation collaboration between Denmark and Brazil which aims to support Brazil in reaching its offshore wind potential through partnerships. As part of the INNOWIND project, this study focuses on a supply chain gap analysis and port infrastructure assessment for upcoming offshore wind projects off the coast of the northeastern Brazilian state of Ceará, where over a fifth of the projects submitted to IBAMA are located [3]. Ceará is also on track to host the first offshore wind turbines in Brazil though a demonstrator project of up to 33 MW [4].

The aim of this study is to identify key trends and larger themes to be used as a springboard to further policy discussions for Brazil's emerging offshore wind market. Key take-aways from each of the report's main sections are summarized below.

Supply Chain Gap Analysis

- As is generally the case for emerging offshore wind markets, Brazil's supply chain will require extensive development if the country is to capture the maximum local benefit from offshore wind. However, Brazil has an excellent starting position compared to many emerging markets due to strong local supply chains in the related sectors of onshore wind and oil and gas.
- Though this report focuses on the state of Ceará, it assesses the entire Brazilian national supply chain as a purely regional supply chain is unlikely.
- To assess key aspects of Brazilian offshore wind supply chain capability and potential, Ramboll developed a set of three criteria: 1) track record in offshore wind, 2) capability in related sectors, and 3) natural localization potential. The methodology is described in Section 4.1.
- The largest opportunities identified in the Brazilian supply chain are where related sectors with skilled workforce also face low to moderate barriers of entry into the offshore wind market, such as turbine blades, turbine towers and onshore electrical infrastructure. However individual companies and institutes looking to invest or expand into offshore wind will need to weigh many factors, including the requirements of waterfront facilities, investments in new equipment and balancing offshore wind's project-based business with their other business units.
- Further opportunities exist for Brazil's offshore logistic vessel fleet, whose utilization will depend on developers' transport and installation strategies, as well as operation and maintenance plans.
- Primary gaps in the Brazilian supply chain include the supply of certain components, which are often in the global offshore wind market supplied from few, select locations and manufacturers or owners, such as turbine nacelles and hubs, subsea cables, as well as turbine and foundation installation vessels.
- Stakeholder engagement throughout drafting this report indicated strong local and global interest in developing the offshore wind industry in Brazil, however unclear regulatory framework and offtake is hindering even the earliest supply chain developments. A key to ensuring the local supply chain's success will be a steady and predictable development pipeline.

Port Infrastructure Assessment

- The port infrastructure assessment focused on ports' suitability as installation and / or operation and maintenance (O&M) ports for offshore wind farms in the waters of Ceará. A port benchmark (Table 6-3) was set based on Ramboll's experience and stakeholder engagement, with criteria for the assessment defined in three categories: 1) maritime access, 2) loading and pre-assembly operations, and 3) storage capacity. The methodology is described in Section 6.2.
- Two potential installation ports were found to be suitable with moderate upgrades required: Port of Pecém and Port of Fortaleza. The primary constraint of both ports is that they can handle only one component campaign (turbine or foundation) at a time, working on a tight,

just-in-time delivery schedule. In their current forms, neither port can support simultaneous campaigns for a single project or multiple offshore wind farms at once.

- Should either the Port of Pecém or Port of Fortaleza wish to transform into a regional hub for offshore wind to support multiple, simultaneous projects as well as provide auxiliary services, this would require major upgrades. In the case of Pecém, a new offshore wind terminal could be constructed, or the current terminal could be connected to the ample onshore area. The Port of Fortaleza will have difficulties to spatially expand operations due to its urban location.
- While Fortaleza is technically suitable, stakeholder engagement indicates that it may not have free capacity. Port of Pecém has been active in investigating potential offshore wind business and is further explored in a case study in Section 6.4.
- Eleven O&M ports were identified which could serve as daily operations ports and / or major repair ports for the Ceará offshore wind farms. Ceará's coast is well covered by potential suitable O&M ports, except for wind farms planned between the port of Camocim and the Port of Paracuru. Should wind farms be installed in this area, a new O&M port would need to be constructed in the long term.

Opportunities for Danish Companies

- Both public and private institutes of Denmark have shown strong interest in Brazil. This report itself and the INNOWIND project are the result of wind energy innovation collaboration between the two countries. The competencies of Danish companies can help to strengthen the Brazilian offshore wind industry, as well as supply chain, through international investment, export of technology and services to Brazil, as well as accelerating development through public and private partnerships.
- There are successful Danish companies in nearly every category discussed in the supply chain analysis (Section 4), with much to offer regarding offshore wind experience and services. Table 5-1 outlines each of these categories with reference to experienced Danish companies and organizations.
- Denmark, as a pioneer in offshore wind and a top-ranked knowledge management and dissemination expert can act as a key resource and partner to Brazil in gathering established markets' experience, insights and knowledge.
- In the short term, the local supply chain must establish technology, facilities and train its workforce. At this stage of market development, Danish companies are often directly providing goods or services to the wind farm, which enables the developer to benefit from the lower pricing of established offshore wind players and avoid putting overly high pressure on the local supply chain.
- Mid-term, the international investment is expected to transition into partnerships and joint ventures with local suppliers. These partnerships will allow the emerging market to continue to develop at appropriate speed, while gathering good industry practices from experienced markets.
- When the Brazilian market has matured, joint ventures and partnerships between local and Danish companies are expected to be well-established and functioning, with the Brazilian partner still continuously benefitting from the knowledge transfer of the Danish partner company. Very successful partnerships may go on to export to further markets together.

Key Factors for Development of Offshore Wind in Ceará

- While the focus of this study is on the supply chain and port assessment, extensive stakeholder engagement has brought attention to other critical needs for the development of offshore wind in Ceará and Brazil. Based on the World Bank's report *Key Factors for Successful Development of Offshore Wind in Emerging Markets*, a selection of these factors are outlined in the final section of the report [5].
- <u>Clear vision and policy targets</u> are required to send a message of commitment to both the local supply chain and the international offshore wind industry of intention to develop. When such long-term visions are paired with defined framework and strategies, suppliers can confidently begin establishing their own pipelines. In setting targets, it must be clear which role offshore wind, compared to other generation sources, is fulfilling at the national and regional level.
- <u>Straightforward sectoral planning and leasing terms</u> are required to ensure harmony between offshore wind as well as other industries and stakeholders in Brazil. Furthermore, developers will need to understand how they will be able to secure seabed leases, while the government simultaneously ensures real commitment through due diligence of the players behind the planning. The commitments needed to apply for an IBAMA license are not significant and many applications to date are viewed by the market as speculative. Going forward, Brazil needs to set the bar for project commitment high enough to quell excessive speculation, but low enough to ensure a high level of competition in the market.
- <u>Paving the route to market</u> must engage developers and shape Brazil's future offshore wind industry by showing a clear route (or routes) to market, which is currently lacking. Potential options include establishing an auction process, providing favorable policies on offtaker agreements, and ensuring competitively priced, stable and reliable finance availabilities.
- <u>Balancing public and private investment</u> will be key in ensuring the emerging industry has clear paths to mitigate the financial risks for investors.
- <u>Ensuring steady development</u> will be a key success factor in establishing a local supply chain especially with the booming potential of Brazil's market. To maintain a healthy, Brazilian supply chain, companies must be able to rely on a clear and continuous pipeline of orders.
- <u>Connecting to the grid</u> must be secured through early planning and infrastructure upgrades for feed-in of power to the transmission grid. Brazil should consider the various benefits of the possible transmission asset ownership scenarios, then clearly define the roles and responsibilities early on.
- <u>Establishing industrial clusters</u> in or around ports helps to alleviate the logistic requirements of offshore wind. With massive components in both dimensions and mass, waterfront manufacturing facilities are frequently needed. At a time when these facilities are being newly established, companies can be incentivized and supported to co-locate at ports with suitable industrial zones, forming impactful offshore wind clusters.

ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
AHTS	Anchor Handling Tug Supply
BNDES	Brazilian Development Bank
BoP	Balance of Plant
CE	(State of) Ceará
CLV	Cable Lay Vessel
COD	Commercial Operations Date
COP	Copenhagen Offshore Partners (company)
CPS	Cable Protection System
CTV	Crew Transfer Vessel
EPE	Energy Research Office of Brazil (Empresa de Pesquisa Energética)
FPSO	Floating Production Storage and Offloading (Unit)
GE	GE Renewable Energy (company)
GEBCO	General Bathymetric Chart of the Oceans
GW	Gigawatt
HLV	Heavy Lift Vessel
HTV	Heavy Transport Vessel
IAC	Inter-Array Cable
IBAMA	Brazilian Institute of Environment and Renewable Natural Resources
JUV	Jack-Up Vessel
LCOE	Levelized Cost of Energy
LiDAR	Light Detection and Ranging
MME	Brazilian Ministry of Mines and Energy
MoU	Memorandum of Understanding
MW	Megawatt
MP	Monopile
nm	Nautical Mile
O&G	Oil and Gas
O&M	Operation and Maintenance
OEC	Offshore Export Cable
OEM	Original Equipment Manufacturer
OSS	Offshore Substation
OSRV	Oil Spill Response Vessel
OSV	Offshore Supply Vessel
OWF	Offshore Wind Farm
PSV	Platform Supply Vessel
R&D	Research and Development
RoRo	Roll-on, Roll-off
ROV	Remote Operated Vehicle
SGRE	Siemens Gamesa Renewable Energy (company)
SOV	Service Operation Vessel
SPMT	Self-Propelled Modular Transporter
T&I	Transport and Installation
TP	Transition Piece
W2W	Walk-to-Work
WTG	Wind Turbine Generator
WTIV	Wind Turbine Installation Vessel

CONTENTS

Photo: Port of Pecém

1 Introduction

1.1 Purpose

The aim of this report is to provide a high-level offshore wind supply chain gap analysis, as well as port infrastructure assessment for upcoming offshore wind projects off the coast of the northeastern Brazilian state of Ceará. The report's intent is to identify trends and larger themes, which can be used as a springboard to further policy discussions, as well as foster supplementary detailed analyses which foster the emerging Brazilian offshore wind market.

This report is part of the "Wind Energy Innovation Collaboration - Brazil and Denmark (INNOWIND Brazil & Denmark)" innovation project, funded by the Danish Energy Agency. The INNOWIND project's purpose is to strengthen the Brazilian wind industry and supply chain through positioning Danish innovative competencies and know-how within wind energy in Brazil, as well as by supporting the development of an innovative energy cluster in the state of Ceará, Brazil. INNOWIND will spur export of Danish wind technology and services to Brazil and increase Denmark's government-to-government cooperation through public-private partnerships.

1.2 Scope

The two primary scopes of this report are a high-level opportunities and gap analysis of the Brazilian supply chain for offshore wind, as well as a high-level analysis of port suitability for offshore wind projects off the coast of the state of Ceará. These two subject areas are supported by additional sections on the current market environment to set the scene and key factors for development of offshore wind in Ceará.

This report concentrates generally on the technical aspects of offshore wind development, so while certain regulatory, stakeholder and commercial aspects are addressed, these are not the focus of the study.

The following content constitutes this report:

Market Environment	The market environment section sets the stage for the supply chain and port analyses, through describing the current market environment in relation to offshore wind. The Brazilian offshore wind industry outlook is briefly described (based on the Brazilian Institute of Environment and Renewable Natural Resources' (IBAMA) publication from April 2022) before offshore wind potential in the state of Ceará is explored [6].
Ceará's Reference Wind Farm	In order to assess component and port requirements, Ramboll defined a reference wind farm based on internal analysis of the planned offshore wind farms in Ceará from the IBAMA publication as well as the industry submissions to IBAMA [6]. This report section further describes the reference wind farm, including brief descriptions of the assumptions and analyses behind the definition.
Supply Chain Gap Analysis	To assess the supply chain available for offshore wind in Brazil, Ramboll broke down the major works of an offshore wind farm into categories. For each category, a high-level, qualitative assessment of the existing Brazilian supply chain for offshore wind was performed. Based on the analysis, key gaps were identified, as well as opportunities.
Opportunities for Danish Companies	A summary of the foreseen Brazilian offshore wind supply chain gaps Danish companies and organizations can help to fill, through

	international investment, export of technology and services to Brazil, as well as accelerating development through public and private partnerships.
Port Infrastructure Assessment	In this section of the report, the available and relevant ports for potential offshore wind involvement are introduced and assessed. General offshore wind port benchmarks and definitions are provided, before shortlisting and evaluating a selection of ports which could serve as installation or operations and maintenance (O&M) port for future offshore wind projects off the coast of Ceará. The section concludes with a brief qualitative case study, examining how the Port of Pecém can be used for offshore wind.
Key Factors for Development of Offshore Wind in Ceará	This section wraps up the findings of this report and highlights which key factors for development are most relevant for Ceará, based on the thorough overview provided in the World Bank Group's 2021 report *Key Factors for Successful Development of Offshore Wind in Emerging Markets* [5].

2

Market Environment

In the early 1990s, Brazil built its first onshore wind turbine in Fernando de Noronha, and Denmark built the world's first offshore wind farm, Vindeby. In the about 30 years since, Brazil continued to pursue development of its rich onshore wind resources. Currently, with over 20 GW of constructed onshore wind power, Brazil ranks sixth globally for holding 3% of the world's total onshore wind installations. In the same timeframe, the first offshore wind farm expanded into a global offshore wind industry. Today offshore wind boasts over 35 GW of operational offshore wind capacity globally, a further 67 GW secured (awarded, pre-construction, under construction or partially operational) and 459 GW in development (scoping, in planning or consented) [7] [8] [9] [10]. These two parallel paths of success are converging, as interest in Brazil's significant offshore wind market potential has grown quickly in recent years.

Brazil's primary motivation for pursuing offshore wind is to increase its domestic energy security. The country already exhibits a strong renewable mix, with 48.4% of the total energy supply coming from renewables in 2020 [8]. Of this 48.4%, over 65% is attributed to sugarcane biomass and hydropower, both energy supplies which are reliant on rainfall [8]. In 2021, the worst drought Brazil has had in nearly a century threatened the energy supply. In response, Brazil has focused on urgently diversifying their renewable energy portfolio. Offshore wind was identified as a key energy source to mitigate the risk of drought on the energy supply. Furthermore, with a significant percentage of the Brazilian population living along Brazil's coastlines, offshore wind offers opportunities for large renewable additions to Brazil's energy mix close to areas with the highest populations.

Brazil, and in particular the state of Ceará, has ideal natural resources for offshore wind, including: relatively shallow water depths, strong and consistent winds and nearly 7,500 km of coastline nationally. Estimates place the total technical offshore wind potential of Brazil between 480 and 700 GW for bottom-fixed offshore sites [1, 2].

Recently, the Brazilian government has begun taking action to turn this potential into mega-watt hours. In 2020, IBAMA launched the Standard Term of Reference for offshore wind projects, guaranteeing greater environmental protection through a well-defined set of technical criteria. The criteria must be used as a reference to determine the socio-environmental impact that the implementation of an offshore wind farm may generate. In January 2022, a decree (n°10.946/2022) was published starting the discussion towards creating a regulatory framework specific for the offshore wind sector, with the intention to cover the technicalities of spatial leasing, among other topics [11]. Establishing a thorough maritime spatial planning process related to offshore wind is still on the governmental agenda as well [12] [13].

For the first time, in August 2021, IBAMA published a map of offshore wind farms which have filed applications to begin the environmental licensing process with IBAMA. The market interest in Brazilian offshore wind has been so high that IBAMA has since issued multiple further revisions of the map. The version considered for this report is the April 13, 2022 version.

A total of 50 projects in six Brazilian states have filed applications. Well-known offshore wind developers, including Equinor and Shell, as well as local developers such as Eólica Brasil, which appear to be completely new to offshore wind energy, have submitted applications [6]. While this is a strong indicator of market appetite, many of these applications are viewed as speculative, as the commitments needed to apply for such a license are not significant. It is still unclear how the sites will be finally assigned (the areas defined in the filed applications increasingly overlap each other) and what the route-to-market options are. Stakeholder engagement throughout drafting this report indicated that the unclear route-to-market, as well as unclear regulatory offtake scheme(s), are suppressing potential supply chain development. However, the local and global interest in the emerging offshore wind market in Brazil is undeniable. Brazil is seen as an emerging market with too large of a potential to ignore. Additionally, certain projects are already exploring research and development (R&D) opportunities, for example the generation and export of green hydrogen to help set Brazil apart from the global offshore wind industry.

Over a fifth of the projects submitted to IBAMA are in the northeastern Brazilian state of Ceará. Off Ceará's 573 km of coastline, the continental shelf ranges from 40 – 100 km in width, with water depths of 5 to 50 m, supplying ample space for up to 117 GW of technically mature bottom-fixed offshore wind [3]. Ceará already has 2.5 GW of installed onshore wind [14] and is also on track to host the first offshore wind turbines in the country. A demonstrator project is under development by the Chinese turbine manufacturer Ming Yang Smart Energy Group Ltd, the Italian oil and gas contractor Saipem SpA, and the Italian-Brazilian company BI Participações e Investimentos [4]. The demonstrator project will include up to three turbines of various capacities, with the largest turbine expected to be a 15 MW turbine.

The state of Ceará is sending positive signals as a potential leading state in the emerging Brazilian offshore wind industry, but further work on supply chain and infrastructure is needed to maintain this momentum. This report explores the strengths and gaps of the local supply chain, potential for international partnerships, necessary port developments, as well as key development factors which will require regulatory and private industry focus.

3

Ceará's Reference Wind Farm

There are currently 11 offshore wind farms proposed in the waters of Ceará, with an additional 12 offshore wind farms proposed in the waters of the two neighboring states (4 in Piauí and 8 in Rio Grande do Norte) [6]. These wind farms are shown in Figure 3-1. While these applications to begin the environmental licensing process with IBAMA are not firm reservations or financial commitments for development, they show strong interest from local and international developers.

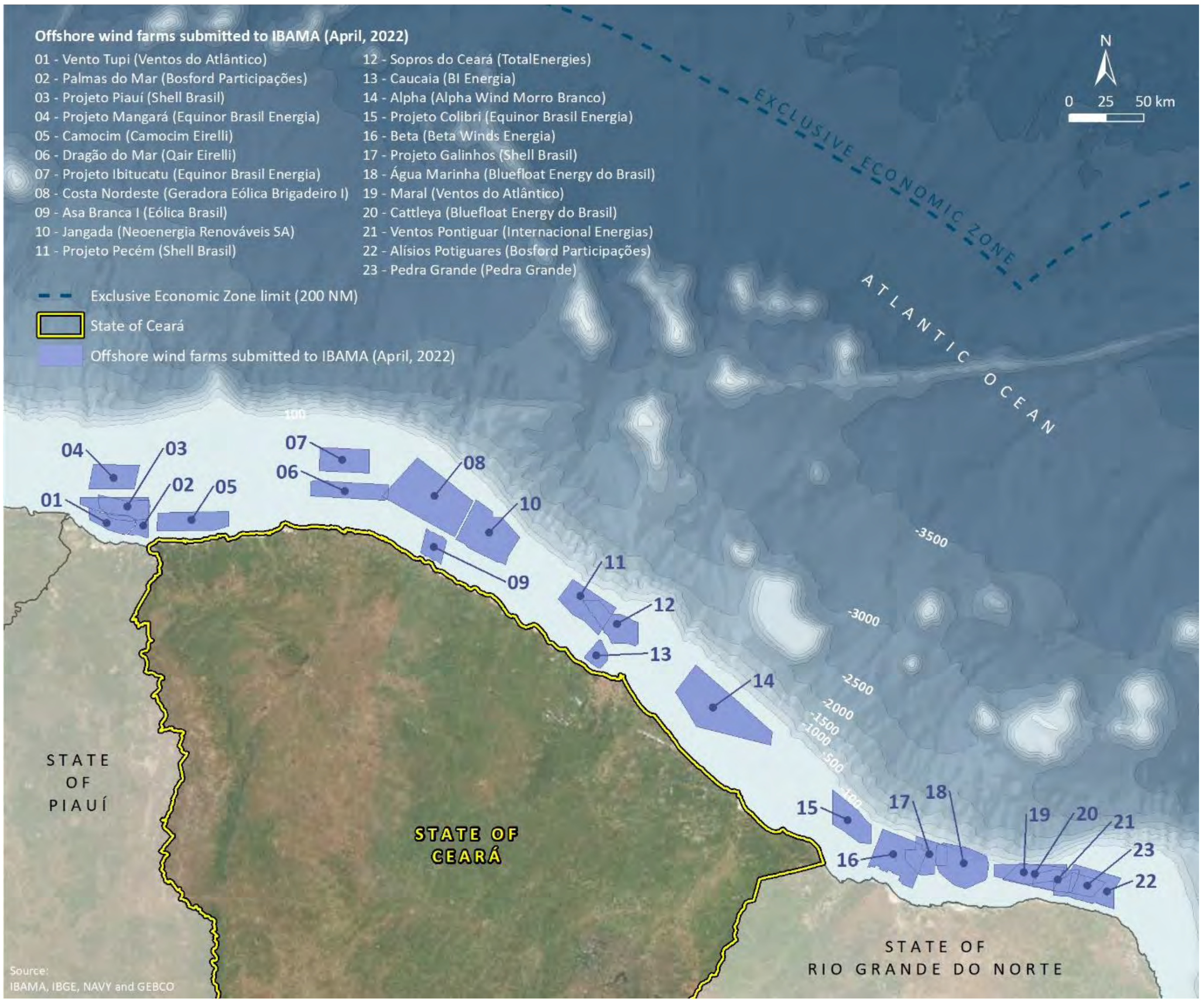


Figure 3-1: Proposed offshore wind farms submitted to IBAMA in the vicinity of Ceará state [6]

IBAMA frequently publishes updates to their map indicating applications submitted. As of writing this report, some developers indicating interest through press releases are not yet included on the IBAMA map. One such developer is OW Brasil, the Brazilian Ocean Winds entity, who submitted five applications to IBAMA with a combined capacity of over 15 GW [15]. One of the applications is in Rio Grande do Norte.

According to Ramboll's analysis, the average wind speed of the sites in Ceará is 8.5 m/s (range from 8.1 m/s to 9.1 m/s)[1] and the average water depth is -22m (range from -8 to -36)[2]. Both the average wind speed and average water depth are well-within the boundaries of technology already in wide-spread use within the global offshore wind industry. Based on this information, Ramboll

[1] Based on data from the Global Wind Atlas at 150m height
[2] Based on data from General Bathymetric Chart of the Oceans (GEBCO)

developed a reference wind farm (Table 3-1) with characteristics that represent a typical potential offshore wind farm in Ceará. The reference wind farm is used in this report to better assess supply chain and port requirements.

Table 3-1: **Reference wind farm's k**ey characteristics

Component	Characteristic	Comment
Wind Farm Location	Offshore Ceará state, up to 50 km from the coast	Based on distance from shore of offshore site applications for the state of Ceará to IBAMA.
Commercial Operations Date (COD)	2030	Typical development times for North Sea countries with mature permitting and route-to-market regimes are in the range of 5-8 years. Uncertainties in permitting and route to market, as currently the case in Brazil, prolong these development times. Ramboll believes 2030 COD would be the earliest reasonably achievable in Brazil.
Site Water Depth	- 22 m	Ceará sites range from -8 m to -36 m, with -22 m as the average across the sites examined
Windfarm Size	500 MW	Frequently utilized baseline for offshore wind farm studies in the industry.
Turbine Capacity	14 – 15MW range	8 of the 11 IBAMA applications filed in Ceará utilize either a 14 or 15 MW turbine.
Foundation Type	Monopile	Assuming suitable seabed conditions, the relatively shallow water depths are favorable for monopiles, which are generally the lower-cost foundation type.

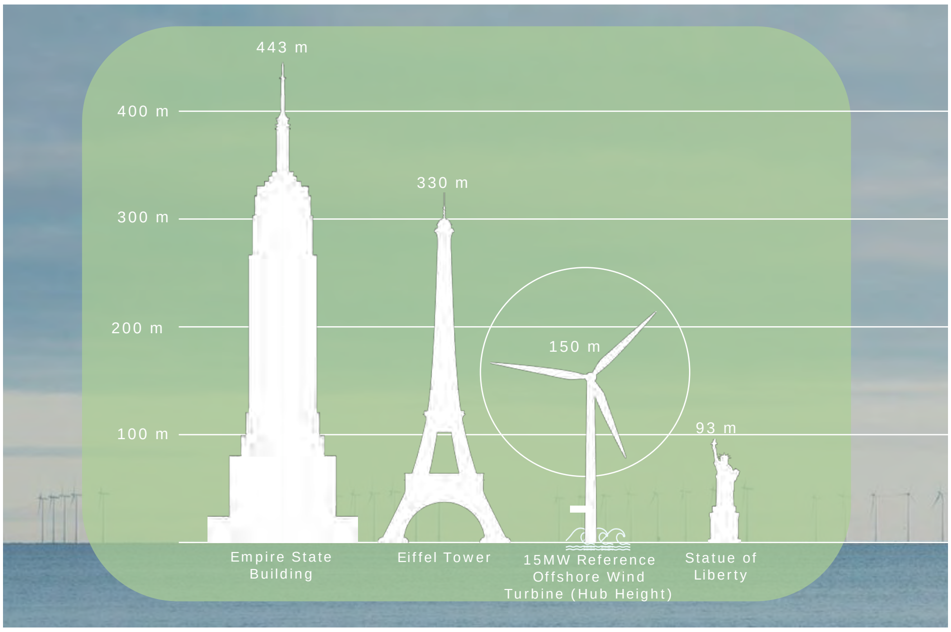


Figure 3-2: Size comparison for 15MW reference turbine used in INNOWIND report

4 Supply Chain Gap Analysis

As is the case for any emerging offshore wind market, Brazil's supply chain will require extensive development if the country is to capture the maximum local benefit from offshore wind. However, with mature supply chains in the related sectors of onshore wind (over 20GW of installed onshore wind at the end of 2021, anticipated to be 40 GW by 2029) and oil and gas (anticipated 5.5 million barrels per day by 2029), Brazil has an excellent starting position compared to many emerging markets [16] [17] [7].

The following sections take a holistic view of the Brazilian supply chain for offshore wind to identify the key anticipated gaps and suggest recommendations on how to close them. Assuming that the Brazilian and Ceará governments lay the regulatory and commercial framework for offshore wind, allowing developers to initiate their projects, certain identified gaps are likely to close on their own as private industry responds to increasing demand from developers. Stakeholder discussions during the writing of this report suggested the unclear regulatory framework in Brazil is a major hindrance in early offshore wind supply chain investments. Other deficiencies will likely need government support to resolve them. In both these cases, the speed and efficiency of closing the gaps can be increased by cooperating with foreign countries and governments experienced in offshore wind.

As per this study's focus on the supply chain's potential to serve offshore wind farms in Ceará, this analysis corresponds to the reference wind farm described in Section 3: a bottom-fixed wind farm using monopile foundations. This study considers that the entire Brazilian supply chain is available to support wind farms in Ceará, as European experience has shown that water transport, even over large distances, is commercially viable.

4.1 Methodology

Ramboll developed a set of criteria to assess key aspects of the Brazilian offshore wind supply chain capability and potential. The analysis starts with breaking down the supply chain of an offshore wind farm into typical phases and categories, as given below in Table 4-1. This high-level breakdown does not represent all phases or categories within an offshore wind farm, rather focuses on key supply chain aspects within emerging offshore wind markets and the most applicable and common technologies. In the case of Ceará, only monopile foundations are considered as per the reference wind farm. More niche solutions, such as gravity-based foundations, are not covered.

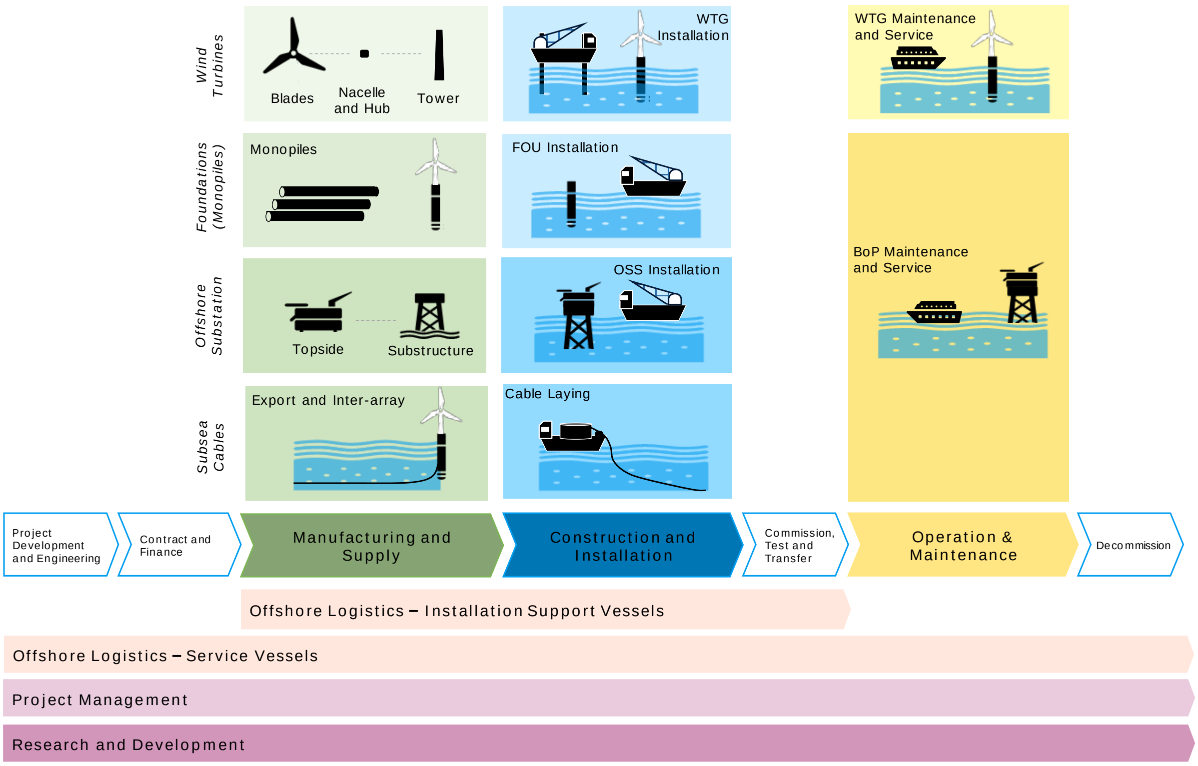


Figure 4-1: Supply chain categories considered in context of an offshore wind farm lifecycle

Table 4-1: Supply chain categories

Phase	Category	Description
Research and Development	Government Initiatives, Non-profits, and Private Industry	Initiatives from the Brazilian, state or local government, non-profit or private industry to support research and development within the context of the global offshore wind industry. For example, offshore wind Power-to-X, or repurposing of oil and gas assets.
Project Management	Service Providers	Companies providing services to support the development, construction and operations of offshore wind farms, including but not limited to, commercial and technical project management services, permitting services, environmental studies, engineering services, etc.
	Offshore Wind Developers	The global and local companies investing in and owning offshore wind farms.
Wind Farm Supply	Nacelle and hub	Fabrication of the nacelle and hub of the wind turbine generator (WTG).
	Blades	Fabrication of the blades of the WTG.
	Tower	Fabrication of the tower of the WTG.
	Foundation (Monopiles)	Fabrication of monopile foundations.

	Subsea Cables	Fabrication of subsea cables, for use as both array and export cables.
	Offshore Substation	Fabrication and onshore pre-assembly of the offshore substation, both topside and foundation.
	Onshore Infrastructure	Supply of required onshore infrastructure, including but not limited to, onshore cables, onshore substation, transmission lines, etc.
Wind Farm Installation	Turbine	Offshore installation of the WTG's tower, nacelle and blades. Typically performed by a jack-up vessel.
	Foundation	Offshore installation of the monopile foundations. Often performed by a jack-up or heavy lift vessel (HLV).
	Subsea Cables	Offshore installation (laying and burial) of the subsea cables, both inter-array and export cables. Typically performed by a cable-lay vessel (CLV).
	Offshore Substation	Offshore installation of the offshore substation, both topside and foundation. Typically performed by a heavy lift vessel (HLV).
Offshore Logistics	Service Vessels	Offshore logistic vessels providing services during construction and operations of an offshore wind farm, such as transfer and accommodation for offshore personnel (crew transfer vessels (CTV) and accommodation vessels), security offshore (guard vessels), etc.
	Installation Support Vessels	Offshore logistic vessels providing installation support services during construction and commissioning of an offshore wind farm, such as tugs and cargo barges, supply vessels and platform supply vessels (PSVs) providing material and supplies offshore, etc.
Operations and Maintenance	Turbine and Balance of Plant Maintenance and Service	Companies offering turbine and / or balance of plant (BoP) maintenance and services for short (0 -5 years) or long-term (5 – 20+ years) contracts. This may be the equipment manufacturer, developer or a third-party provider.

Each category is assessed against a set of three criteria:

- Track record in offshore wind
- Capability in related sectors
- Localization potential

4.1.1 Track Record in Offshore Wind

Experience in completed offshore wind farms is the golden standard in demonstrating capability. While this is not frequently seen in emerging markets, there is occasionally the case where local companies are already exporting services or goods to offshore wind farms in other countries. First local experiences in offshore wind can often be gained via demonstrator projects. The criterion "track record in offshore wind" has been reviewed using the analysis levels as summarized below in Table 4-2.

Table 4-2: Analysis levels for track record in offshore wind

Criterion	Analysis Level	Description
Track record in offshore wind	None or very low	No experience in offshore wind
	Low	Low experience in offshore wind or additional specialized equipment needed
	Moderate	Moderate experience in offshore wind
	Extensive	Extensive experience in offshore wind, global-level supplier

4.1.2 Capability in Related Sectors

Related sectors are those with equipment, facilities and/or skilled workforces which can also be applied to offshore wind. In the best case, certain aspects from other industries can be directly applied to offshore wind without significant investment, for example, in new equipment or upgraded facilities. Jacket foundations, for example, can technically be manufactured easily by companies experienced in manufacturing jackets for the oil and gas industry, but large adaptations will be necessary to enable serial production. In other cases, companies may have to invest in new or upgraded facilities or equipment, or train workforce to make a new or related product. Where there is no capability in related sectors, this may be linked to historical lack of workforce, lack of raw materials or lack of related sector experience. While related sectors can be enablers in more agile buildup of a local supply chain, their existence should not be viewed as a guarantee for a local offshore wind supply chain. Many technical, economic and political factors play into a supply chain's success.

Key related sectors for offshore wind in the Brazilian context are onshore wind and oil and gas. Onshore wind is a well-established industry in Brazil with proven capacity factors. Onshore wind in Brazil reached over 20 GW in 2021 [7]. In terms of turbine technology, offshore wind is a closely related to onshore wind, however the size of offshore wind's turbines and all related components are significantly larger.

Stakeholder engagement during the writing of this report indicated onshore wind is Brazil is presently installing 3.5 – 5 MW class turbines, with the first 6.2 MW turbine soon to be installed. The offshore wind turbine considered for this report is a 15 MW turbine, as further described in Section 3. The difference in machine size will present numerous challenges for the related sector of onshore wind to transition into offshore wind. Three examples of such challenges are listed below:

- Fabrication of certain components, such as the wind turbine generator, as well as certain raw materials may be able to scale to meet the offshore wind industry's needs. However, such scaling would require investments into facilities and equipment, as the new offshore manufacturing facilities must be located on a waterfront due to the components being too massive for land transport. On the positive side, the size of investment for training the local workforce may be minimal due to existing experience with onshore wind turbines.
- Pre-assembly and installation will diverge significantly between onshore and offshore wind. Examples include onshore wind cranes not having capacities to lift offshore wind components, the addition of offshore wind ports and vessel spreads, as well as offshore equipment, which is not applicable to the onshore wind industry.
- Finally, maintenance requirements and logistics present both synergies as well as differences between the sectors. The emerging offshore wind sector will benefit from Brazil's onshore wind experience in wind park monitoring as well as maintenance campaign planning. Performing maintenance offshore requires vessels and expertise not currently held in onshore wind.

The second related sector is Brazilian oil and gas. In 2020, oil and gas (O&G) represented nearly 45% of Brazil's total energy supply [8]. Brazil's Ten-Year Energy Expansion Plan expects oil production to reach 5.5 million barrels per day by 2029, which would nearly double 2018 barrel per day values [17]. This established and growing industry can certainly lend a hand to the emerging offshore wind industry, though also prove to be in competition for example for training offshore workforce or vessels. Synergies can be found across planning, manufacturing, installation and maintenance from service providers and developers who are already experienced in the marine environment of Brazil. However, challenges are also expected, namely transitioning custom oil and gas projects into serial production offshore wind projects, as well as the large differences in project economics. Four examples of such synergies and challenges are listed below:

- The workforce and equipment (as well as certain results) for offshore survey campaigns from oil and gas can greatly benefit the offshore wind sector, though may require expansion to include more in-depth offshore wind condition and wind measurement studies.
- Similarly, certain manufacturing workforce skills, facilities and equipment can support offshore wind. Potential candidates include jacket foundations for wind turbines, subsea cables and offshore substation topsides. The largest challenge for manufacturing will be the transition away from custom, oil and gas components, into serial production required by offshore wind.
- Installation for both the O&G and offshore wind industries handle large structures, as well as cables offshore, however detailed vessel requirements for offshore wind campaigns, such as crane capacities, will differ from oil and gas requirements.
- Finally, it is expected that offshore wind operation and maintenance (O&M) will benefit from oil and gas experience in Brazil. Both industries operate and maintain offshore assets, with all associated challenges of harsh offshore conditions. Furthermore, synergies may be found in the workforce's experience, the facilities dedicated to O&M logistics and equipment.

The criterion "capability in related sectors" has been reviewed using the analysis levels as summarized below in Table 4-3.

Table 4-3: Analysis levels for capability in related sectors

Criterion	Analysis Level	Description
Capability in related sectors	None or very low	No capability in related sectors
	High barriers	Companies in related sectors that can enter market with high barriers
	Moderate barriers	Companies in related sectors that can enter market with moderate barriers
	Nearly market ready	Companies in related sectors that enter market without significant barriers

4.1.3 Natural Localization Potential

The previous two criteria consider the supply potential, but if this potential is to be realized, several other economic factors come into play. These broad considerations are summarized as "localization potential." The analysis considers natural localization potential, which is local supply chain development that can be expected to be simply driven by the market, without local content requirements or similar incentives. In the absence of specific build-out scenarios, supply chain development can be best understood as being driven by volumes of installed capacity, or a clear pipeline of projects that the market deems reliable. Ramboll assessed natural localization potential based on four project pipeline GW ranges:

1. Late Localization: After surpassing the 10 GW mark, the competitive price pressure increases further as new market entrants are attracted and economies of scale become powerful. Successful local companies may press on further into export markets.
2. Mid-Term Localization: After the first few wind farms have been installed and proved successful, the second movers and local suppliers with higher barriers to entry will increasingly join the supply chain in the mid-term phase (3-10 GW). These barriers to entry may include expanding production lines, opening new premises or adding workforce. In this phase, the industry is maturing and increasing price competition is driving down costs.
3. Early Localization: In the early phase (up to 3 GW) of offshore wind establishment in Brazil, the first movers will be those supply chain participants whose local participation is essential, such as ports, or whose involvement is already of clear economic advantage.
4. Local capacity exists: Local capacity already exists and therefore the natural localization of a local supply chain is complete. Potential to become a global exporter for the offshore wind industry.

The criterion "natural localization potential" has been reviewed using the analysis levels as summarized below in Table 4-4.

Table 4-4: Analysis levels for natural localization potential

Criterion	Analysis Level	Description
Natural localization potential	Late	Late natural localization, cumulative installed capacity of 10+ GW Wind farms supplied locally by: • A broad range of established and experienced offshore wind suppliers, delivering at consistently decreasing cost • New market entrants or local subsidiaries of suppliers with high barriers to entry
	Mid-Term	Mid-term natural localization, cumulative installed capacity of 3-10 GW Wind farms supplied locally by: • Fast follower suppliers with some natural competitive advantages can be applied in this area, with low or moderate investment • An increasing number of local companies, which come under pressure to deliver at lower cost
	Early	Early natural localization potential, cumulative installed capacity of up to 3 GW Wind farms supplied locally by: • Necessary first movers, who must be local • Companies with offshore experience or capabilities in related sectors without significant barriers • Local companies with natural competitive advantages, which can easily be applied to offshore wind
	Local capacity exists	Local capacity already exists, and industry is strongly utilized. Potential to become a global exporter for the offshore wind industry.

4.2 Gap Analysis

In the sections below, each category is evaluated against the three criteria, and the results summarized.

4.2.1 Research and Development

The emerging offshore wind markets in Brazil and Ceará not only hold potential to develop impressive project pipelines and supply chains, but also opportunities to lead the global offshore wind industry through early identification and implementation of research and development projects. Beginning and furthering research and development (R&D) of an industry brings value to a country's supply chain and workforce. Examples globally include offshore wind power-to-x projects, installation optimizations, energy island developments, repurposing of oil and gas assets, autonomous inspections and digital twin monitoring solutions.

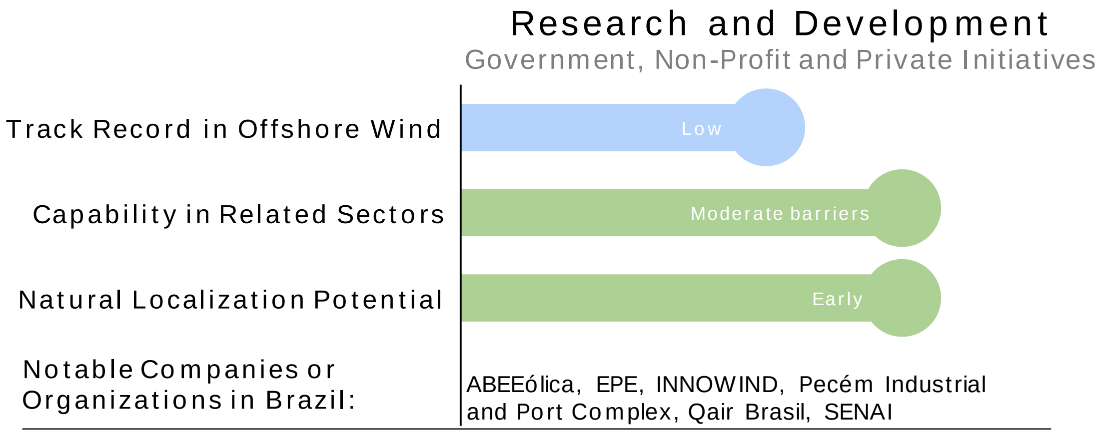


Figure 4-2: Summary of Criteria Score for Research and Development - Government, Nonprofit and Private Initiatives

Offshore wind is currently being furthered in Brazil and Ceará through governmental and non-profit agencies, which are conducting market research and releasing publications with the aim of increasing the knowledge in the Brazilian offshore wind sector and fostering its growth. In 2020, for example, government agency EPE released the Brazilian Offshore Wind Roadmap, orienting the stakeholders by presenting the main challenges that the industry expects. In 2022, the project under which this study is written, INNOWIND, which is funded by the Energy Cluster Denmark and the State of Ceará, contracted this study along with additional initiatives. The purpose of the project is to strengthen the Brazilian wind industry and supply chain through positioning Danish innovative competencies and know-how within wind energy in Brazil, as well as to support the development of an innovative energy cluster in the state of Ceará, Brazil.

Brazil's wind energy sector is represented by the country's wind power trade group, ABEEólica, which heavily contributes to the recognition of wind energy as a strategic source to the composition of the national electrical mix. Their membership includes over 100 companies focused on the wind industry, with an offshore wind working group in place since 2017. While ABEEólica's primary focus thus far has been onshore wind, their Annual Wind Power Generation Reports, InfoWind fact sheets, and Technical Works publications could be extended to include offshore wind. Furthermore, ABEEólica is one of the partners of the Brazil Offshore Wind Summit in June 2022 hosted by the Global Wind Energy Council (GWEC).

Moreover, the Brazilian government and nonprofits have promoted successful programs for related industries in the past. The onshore wind industry in Brazil was jump-started through the PROÉOLICA and PROINFA programs (2001 and 2002), together with the publication of the first Brazilian Atlas on Wind Energy Potential. Since then, the onshore sector has expanded massively, also in part thanks to investment from the National Brazilian Development Bank (BNDES).

Brazil is also already pursuing Green Hydrogen production from offshore wind through a Memorandum of Understanding (MoU) with Qair Brasil. In a 2021 press release, the plans for a Green Hydrogen production plant or "Green Hydrogen Hub" at the Pecém Industrial and Port Complex, with electricity supplied partially from the future Dragão do Mar offshore wind farm was announced [18]. With a planned investment of nearly 7 billion dollars, this R&D project could be a leading example for the global offshore wind industry of Power-to-X production plants.

An example of government funded research to promote offshore wind development is seen in the SENAI Institute for Innovation in Renewable Energies' investigation of the areas with the strongest offshore wind potential on behalf of the Ministry of Science, Technology and Innovations. The study is covering the waters of Rio Grande do Norte, Ceará, Piaui, Maranhão, Pará, and Amapá [19].

As the offshore wind industry emerges in Brazil, there is a clear opportunity for early initiation of programs focused on furthering research and development in the offshore wind market as a whole. One example in Brazil is the Green Hydrogen Hub. Such R&D initiatives include extremely diverse content and organizational possibilities. Examples can include specific programs to develop technological innovations, academic programs focused on the industry, infrastructure research programs such as improving the potential of a port cluster, and many more. A few concrete examples of research and development programs established in other countries by government and nonprofit agencies are listed in Table 4-5.

Table 4-5: Example research and development programs from governmental and non-profits in offshore wind

Program	High-Level Description	Link
Energy Cluster Denmark	A member-based national organization focused on facilitating industry driven innovation projects and collaborations in the Danish energy sector.	https://www.energycluster.dk/en/
Megavind	A platform for the Danish public and private wind energy community to collaborate on research and innovation in the wind energy industry.	https://megavind.winddenmark.dk/
National Offshore Wind Research and Development Consortium	A non-profit program focused on the offshore wind industry in the United States to further R&D activities and reduce levelized cost of energy (LCOE).	https://nationaloffshorewind.org/

Offshore Renewable Energy Catapult	A program established by the government of the United Kingdom focused on technology innovation and research for offshore renewable energy.	https://ore.catapult.org.uk/
Fraunhofer Institute for Wind Energy Systems	The Fraunhofer Institute is a German non-profit organization, which has focused a branch of their research projects on R&D for wind energy systems.	https://www.iwes.fraunhofer.de/en.html

4.2.2 Project Management

All lifecycle phases of an offshore wind farm project require project management, though which party manages which scopes differs greatly from project to project. Certain developers have large in-house teams prepared to manage all development, construction and operation tasks, while other developers utilize service providers for the majority of project management and development. The mix is often dependent upon a project's or developer's capabilities, contracting strategy and upcoming project pipeline.

4.2.2.1 Service Providers

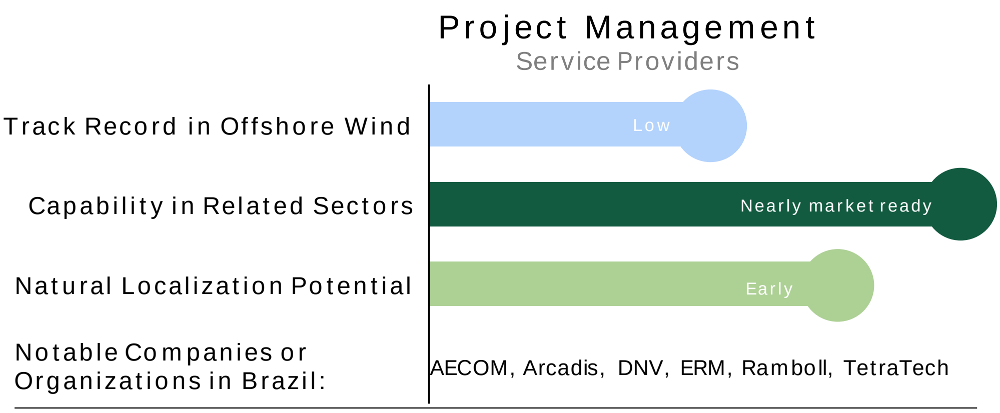


Figure 4-3: Summary of Criteria Score for Project Management - Service Providers

The term "service providers" covers a vast scope of areas and can generally be defined as the companies who provide services rather than goods. Service providers include both more general project management and technical package management services, as well as specialist services, including but not limited to engineering services, regulatory and permitting support, certification management, commercial advisory, insurance management, environmental consultancy, site surveys such as soil investigations, wildlife surveys, floating LiDAR campaigns and unexploded ordnance surveys, etc.

These services are well-established for Brazil's related sectors, such as onshore wind and oil and gas. For example, Brazil's wind power trade group, ABEEólica, has 23 members which allocate themselves under the category "Engineering, Consulting and Construction”, who may be able to extend their services to provide their expertise to the offshore wind industry. However, they will need to acquire specialized knowledge for offshore wind from outside of Brazil. Service providers like AECOM, Arcadis, DNV, ERM, Ramboll and TetraTech are multinational companies with offices also in Brazil, some of which have provided offshore wind services elsewhere across the globe and are capable of quickly transferring knowledge to their existing Brazilian subsidiaries. Necessary equipment, for example for offshore soil investigations, is mostly already available in Brazil due to the parallel sectors, in this case oil and gas.

4.2.2.2 Project Developers

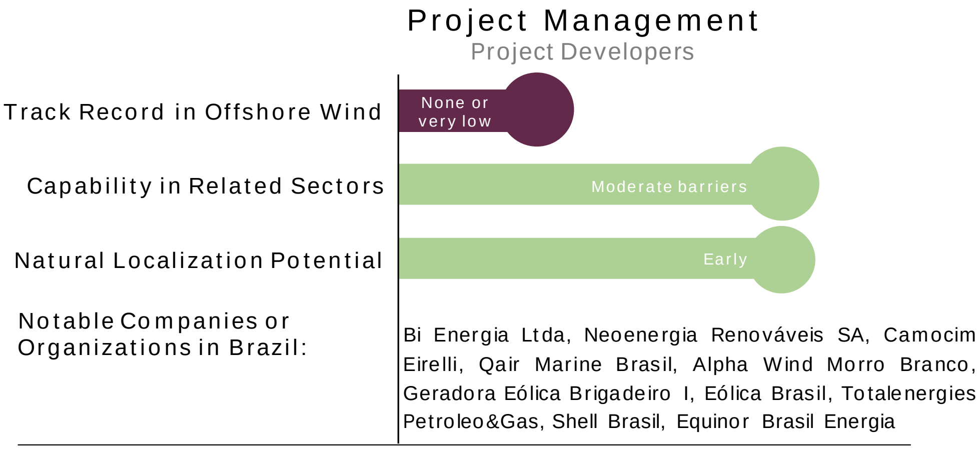


Figure 4-4: Summary of Criteria Score for Project Management - Project Managers

Project developers in offshore wind are the responsible parties for all early-stage activities, such as design and engineering, and financing and, in many countries, site surveys and permitting works. Many developers continue with the project to construct, own and operate the offshore wind farm. Historically developers include large utilities in related sectors expanding their energy portfolios, energy infrastructure companies aiming to develop and sell the assets, as well as joint ventures and strategic partnership combinations.

Based on IBAMA’s publications, global companies such as Equinor, Shell and Neoenergia are planning to develop offshore wind farms in Brazil, as well as Brazilian developers such as Eólica Brasil. The related sector of onshore wind in Brazil already boasts strong project developers, including but not limited to Casa dos Ventos, Omega, Ecoenergia, Enel, and EDPR. The cost of a typical offshore wind farm is several orders of magnitudes larger than the cost of typical onshore wind farm and the necessary liquidity especially in early development is likely to be a high barrier to onshore developers entering the market alone. Further high barriers may include the addition of the complex marine environment and the increased scale of both components and the internal organization size for management and maintenance. Furthermore, stakeholder engagement indicated that the largest local onshore developers are not entering the offshore market, as the Brazilian onshore wind market potential is keeping the developers' project pipelines full.

Brazilian oil and gas developers are also beginning to explore offshore wind. One example is Petrobras, who originally signed a MoU with Equinor in 2018 for joint development of offshore wind in Brazil. In May 2022, the offshore wind farms Aracatu 1 and 2, with a joint capacity of over 4 GW, were announced as under environmental feasibility evaluation by Equinor and Petrobras [20]. When entering the offshore wind market, oil and gas developers may struggle to adapt from their usual, specialized custom-built projects with more generous margins, to offshore wind's serial production and installation projects, with lower margins.

Though barriers are viewed as high for new developers entering the offshore wind market, partnerships with experienced developers reduce entry to market to moderate barriers. Collaboration between experienced and local entities allows for mitigation of risks, transfer of knowledge, and overall acceleration of development, supply and installation of Brazil's first offshore wind farms. The applications submitted to IBAMA already show partnerships forming in Brazil's emerging offshore wind market.

4.2.3 Wind Farm Supply

When considering development of a supply chain, wind farm supply considerations (often also referred to as "fabrication" or "manufacturing") frequently are the first to spring to mind. While related sectors may ease the transition into offshore wind component supply, developing strong supply capabilities require suitable facilities and equipment, trained workforce, and access to raw materials. Though perhaps the most challenging to establish, offshore wind farm supply accounts for the largest percentage of job creation in the lifecycle of a project. A 500 MW offshore wind farm creates about 2.1-million-person days of work, 59% of which lies with manufacturing and procurement [21]. A key to developing a strong and local supply chain is project continuity. Fabricators require a full and continual pipeline of offshore wind projects to ensure their (often) large investments required to move into offshore wind can be profitable. As offshore wind is a project-based business, continuity can often be a challenge, especially in emerging markets.

4.2.3.1 Nacelles and Hubs

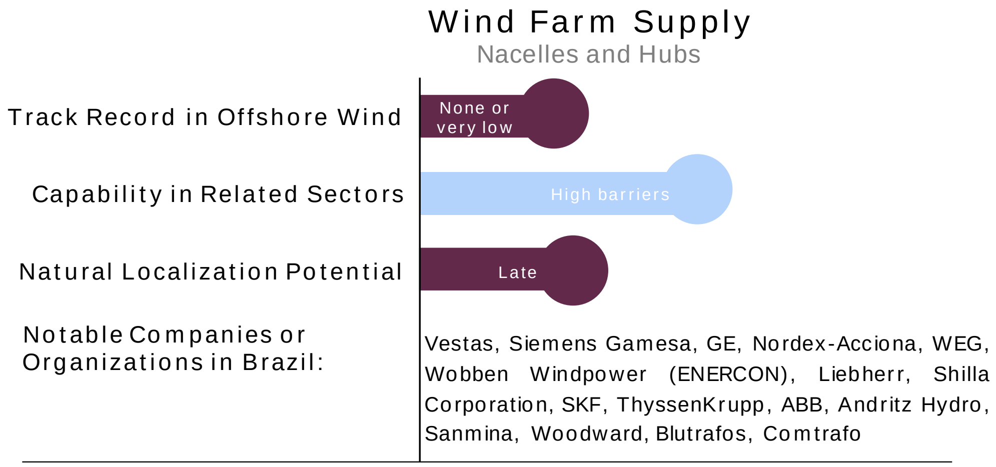


Figure 4-5: Summary of Criteria Score for Wind Farm Supply - Nacelles and Hubs

The nacelles and hubs of an offshore wind turbine house the key power generating elements, which convert kinetic wind energy into electrical power. The hub can be viewed as the 'front' of the nacelle, where the blades connect via rotor and main shaft. Within the nacelle are the power generating components of the wind turbine, such as the drivetrain, which is comprised of the gearbox and the generator. These elements of the wind turbine are high value components for the wind turbine manufacturers, who are trending towards vertical integration.

The strongest players in offshore wind nacelle and supply are the primary three offshore wind turbine manufacturers: Vestas, Siemens Gamesa Renewable Energy (SGRE) and GE Renewable Energy (GE). Regarding their track records in offshore wind across the globe, Vestas brings together more than 25 years of experience, +7 GW and +1,500 turbines installed across 41 projects offshore [22]. SGRE is a pioneer in offshore wind with 15 GW of offshore wind capacity globally and 70% of market share in Europe [23]. GE boasts a strong project pipeline for their Haliade-X turbine, especially in the US offshore wind market [24].

Each of these players has already established their manufacturing capability in Brazil within onshore wind [25]. Vestas manufactures and assembles nacelles and hubs in the state of Ceará [26]. SGRE produces nacelles, hubs and power conversion systems in the state of Bahia [27]. Finally, GE assembles turbines, also in Bahia, with more than 60% of its components provided by Brazilian suppliers [28].

Additional onshore wind turbine suppliers also add to Brazil's nacelle and hub experience. Nordex-Acciona assembles nacelles in its own facility in Bahia [29]; WEG has multiple factories in Brazil, with units in the southern state of Santa Catarina producing hubs, generators and nacelles [30]; Wobben/ENERCON, in Brazil since 1995, has a factory in the state of São Paulo [31]. However, none of these manufacturers are expected to enter the offshore wind market globally.

Brazil also has numerous manufacturing facilities that are focused on subcomponents for the onshore wind market. Over 100 manufacturers can be found in Brazil, with their factories located in the northeastern and southern regions [25]. The main suppliers of bearings (Liebherr Brasil Eireli, Shilla Corporation, SKF and ThyssenKrupp) and generators (ABB Ltda, Andritz Hydro S/A, GE Power Conversion Brasil Ltda and Ingeteam Ltda) are located in the state of São Paulo. Converters are supplied by all previously mentioned, plus Sanmina and Woodward, while transformers are supplied by ABB Ltda, SGRE, WEG, Blutrafos and Comtrafo [25].

While the onshore wind industry well-suited to serve Brazil locally, offshore wind increases the size of the nacelle and hub components significantly, which prevent current manufacturing facilities from being used for offshore wind. The overland transportation of components for 15 MW machines, as assumed in this report, is not economically nor technically feasible. Large investments in new, waterfront fabrication sites will be necessary. Stakeholder engagement during the drafting of this report further indicated a push from offshore WTG manufacturers and their primary suppliers globally to focus fabricating their components at select manufacturing sites globally, rather than investing in and building-up new waterfront facilities across many emerging markets. Due to both this global market trend, as well as the large investments necessary, localization of nacelles and hubs is expected quite late, only with a high-volume project pipeline.

4.2.3.2 Blades

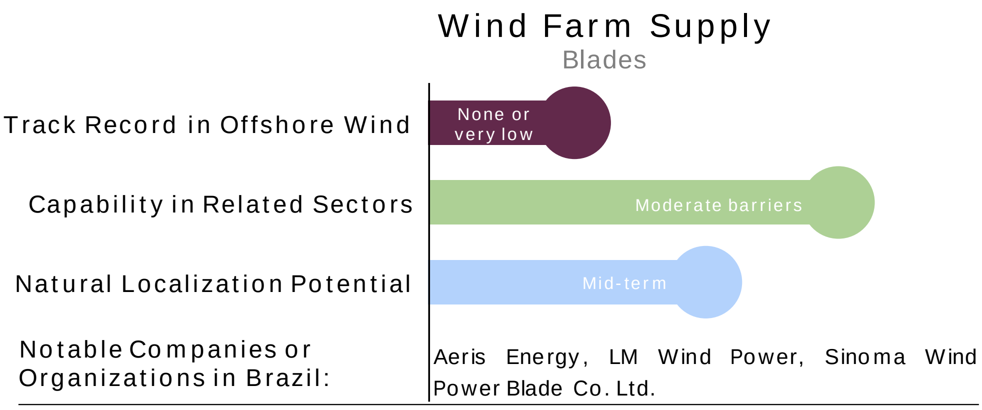


Figure 4-6: Summary of Criteria Score for Wind Farm Supply - Blades

Blade manufacturing in offshore wind is largely through exclusive and established supplier relationships with the turbine OEM, as it is viewed as a strategic element of their value chain. High technological barriers to entry, as well as the value of intellectual property associated with blade design and fabrication contribute to the push to serve markets from established supply chains. Blade sizes for modern offshore wind turbines, such as the ones considered in the reference offshore wind farm in this analysis, are up to 125 m in length and 80 metric tonnes in weight. This poses additional production and logistic challenges, which has limited supply chains in established offshore wind markets primarily to coastal locations.

Unlike offshore wind, many of Brazil's onshore wind turbine blades are subcontracted out to the Brazilian company Aeris Energy, the biggest wind turbine blade manufacturer in Latin America. Aeris Energy currently supplies wind turbine blades for Vestas, Nordex-Acciona, WEG, GE and SGRE [32]. In 2021, Aeris manufactured blades over 80 meters in length for Nordex-Acciona that were shipped directly from the Port complex of Pecém, CE, where Aeris Energy's factory has an annual production capacity of 9 GW (2021) [33].

Other blade manufacturers are also located in Brazil supplying the onshore wind industry. LM Wind Power's factory is localized in the Port complex of Suape, in the state of Pernambuco. LM Wind Power has recently expanded its production capacity for blades over 60 meters in length [34], besides securing a partnership with Vestas for the production of the V150-4.2 MW turbine blades, to begin in mid-2022 [35]. Also, the government of Bahia has recently started negotiating with the Chinese engineering firm Sinoma to establish their first blade factory outside China in Camaçari, BA [36].

With its robust onshore wind industry, Brazil's workforce is experienced in blade manufacturing, but investments in new waterfront manufacturing and additional equipment for larger blade sizes will be needed for offshore wind. An additional challenge Brazil will face in localizing blade fabrication is market fragmentation. Blades for offshore wind turbines are specific to a turbine model, meaning that blade manufacturers are making market entry decisions not based on the total installed capacity, but on the total installed capacity of a certain wind turbine model. It is unclear to which extent OEMs would be willing to deviate from their established supply chains to use a local and shared supplier, for example Aeris Energy. Nonetheless, it is expected that these barriers can be overcome more easily than emerging markets without a similarly trained workforce.

4.2.3.3 Towers

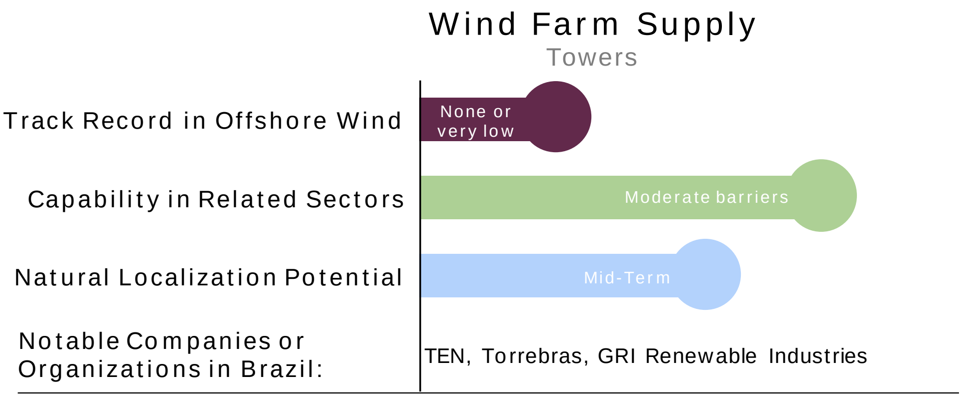


Figure 4-7: Summary of Criteria Score for Wind Farm Supply - Towers

Towers have the function of carrying the nacelle and transmitting loads from the rotor-nacelle assembly into the foundation. In offshore wind, towers are usually manufactured in three or four sections, which are then transported to the project's marshalling port, before pre-assembly and load out for offshore installation. Unlike onshore wind turbines, where concrete towers can also be utilized, the towers for offshore wind turbines are fabricated from steel. As with all other components, coastal tower manufacturing facilities are needed.

Brazilian onshore wind does have a track record in steel tower manufacturing, however at smaller dimensions than required for offshore wind. Torres Eólicas do Nordeste S.A. (TEN), is a Brazilian company that deals with the structure, coating and internal components of steel towers. It has an inland factory in Jacobina, Bahia, a region with a high concentration of Brazil's onshore wind farms [37]. The inland location of TEN is unlikely to be feasible for offshore wind tower components. Torrebras is another company in the onshore wind energy steel tower manufacturing market since 2013, with a factory in Bahia, about 20 kilometers inland. Finally, GRI Renewable Industries headquartered in Madrid, Spain has 16 wind energy component manufacturing facilities in eight countries, including GRI Towers Brazil. Located in the Brazilian state Pernambuco, GRI Towers Brazil currently manufactures onshore towers of up to 5m diameter and 80-tons per section in weight [38]. While offshore tower sizes are significantly larger, GRI Renewable Industries announced in 2021 that they will build and open a new offshore tower fabrication site in the United Kingdom [39].

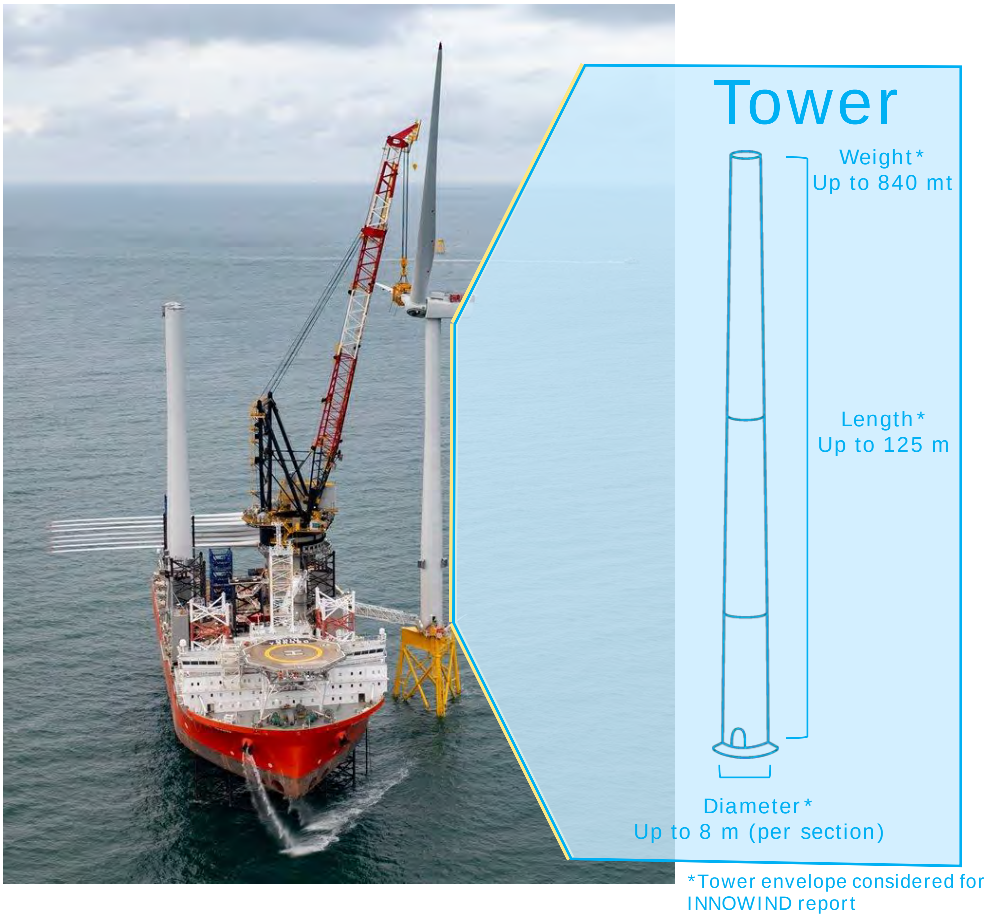


Figure 4-8: Exemplary tower dimensions considered for the INNOWIND report. Installation photo credit Cadeler [70]

In addition to experience in onshore wind towers, Brazil has a local steel industry, which is an advantage many established tower manufacturing markets do not have. Brazil is known for making high quality carbon steel slabs as a semi-finished products for steel products. Companies such as CSP, who are located in the Port of Pecém complex, as well as Usiminas and Grupo Aço Cearense are good examples of potential suppliers of the raw materials for towers [40] [41].

The Brazilian workforce is relatively well placed from the experience in onshore wind and the local steel industry, however tower production for offshore wind will require significantly larger steel structures than currently fabricated in Brazil. Offshore wind tower diameters currently reach up to 8.5m. Upgrades to facilities and equipment, as well as the logistical requirement of waterfront fabrication to transport the large components may slow down the localization of offshore wind tower supply.

4.2.3.4 Foundations (Monopiles)

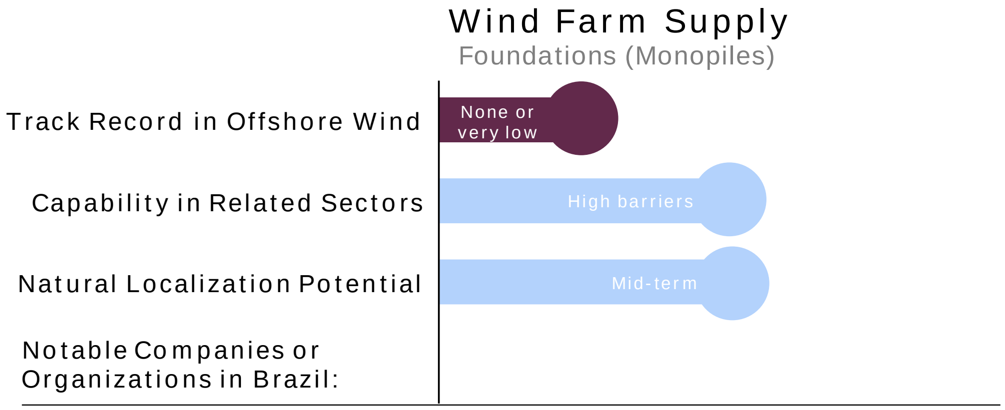


Figure 4-9: Summary of Criteria Score for Wind Farm Supply - Foundations (Monopiles)

Turbine foundations come in many different variations, such as monopiles, pin-piled jackets, suction bucket jackets, gravity-based foundations, various forms of floating foundations and others. As stated in Section 3, the reference wind farm for this report utilizes monopile foundations, as the water depths off the coast of Ceará allow for this commonly used foundation type. Monopiles are the most frequently used foundation type in the global offshore wind industry, as they are easier to manufacture and install in the volume often seen in offshore wind farms than jacket foundations. Monopiles are rolled tubular sections, which are later welded together. Based on the environmental conditions and turbine selected, the diameter and wall thicknesses of the monopiles vary. The interface between wind turbine generator and monopile is known as the transition piece (TP). For a 15 MW turbine, as referenced in this report (Section 3), the monopile’s top diameter is often similar to the bottom tower diameter to avoid additional conical transitions in the TP. This can be estimated around 7.5m to 8m. The bottom diameter of the monopile is driven by water depths and soil – assuming sand and clay, the bottom diameter could be estimated around 8.5 – 10m.

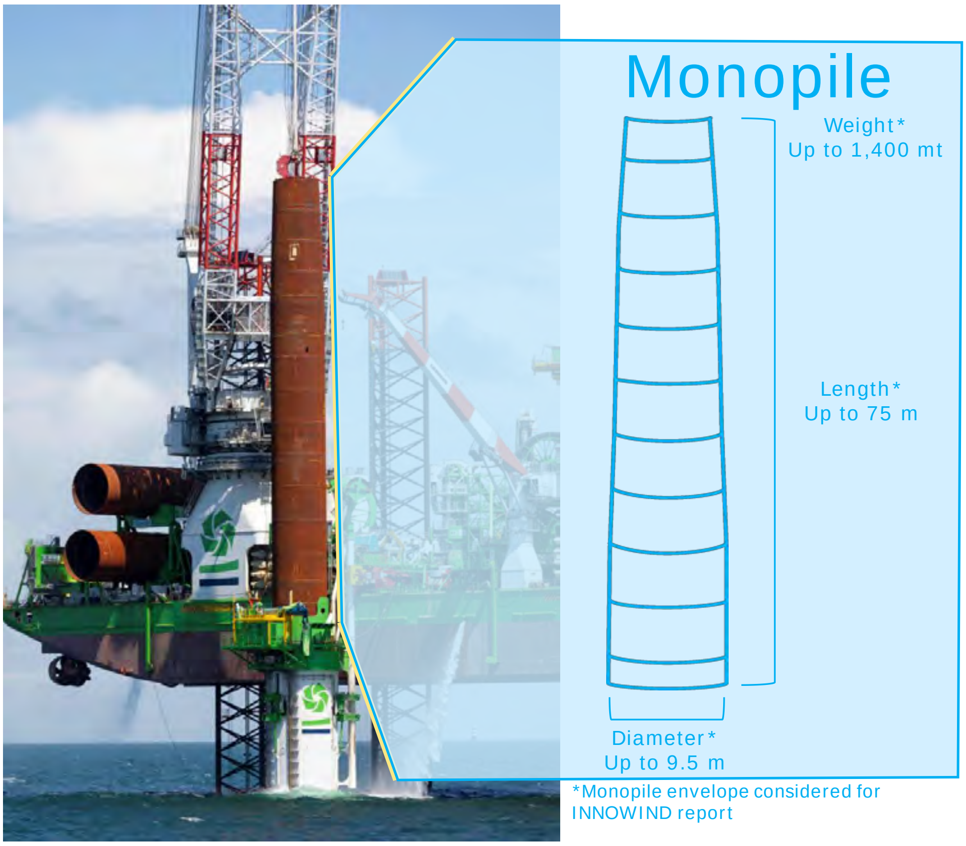


Figure 4-10: Exemplary monopile dimensions considered for the INNOWIND report. Installation photo credit DEME Offshore [69]

While Brazil does not have a monopile industry, any suppliers of rolled tubes may be able to enter the offshore wind market with relatively low barriers, however it is expected that new, waterfront facilities will be required to supply the required offshore wind dimensions and transport the foundations. For example, potential suppliers may include onshore wind turbine tower manufacturers. In Europe, a few tower manufacturers are interested in entering the monopile market, for example GRI Renewable Industries and Haizea in Spain. The primary technical challenge in such a transition is the rolling of the plates, with significantly larger diameters and wall thicknesses. Especially the bottom diameters described above and overall wall thicknesses far exceed classic onshore turbine towers. A secondary challenge is the logistics and storage of the larger components. Large investments in waterfront facilities will be necessary to transport monopiles, as well as investments in equipment are needed, such as sufficiently rated self-propelled modular transporters (SPMTs), as well as upgrades to the storage areas to ensure proper load bearing capacity may be necessary. Monopiles produced for offshore wind are not possible to be transported via road or rail, therefore fabrication facilities require access via vessel or barge.

Another supporting factor to local foundation supply is the local steel industry. As mentioned in the previous section on turbine towers, Brazil is known for making high quality carbon steel slabs as a semi-finished products for steel products. Companies such as CSP, who are located in the Port of Pecém complex, Usiminas and Grupo Aço Cearense are good examples of potential suppliers of the raw materials for monopiles [40] [41].

Although in Brazil no steel monopile manufacturing currently exists, the country has most of the necessary characteristics for a local monopile industry to begin. Large investments in new, waterfront facilities for transport, as well as equipment for larger diameters and wall thicknesses are required in order to serve the monopile sizes of the offshore wind industry.

4.2.3.5 Subsea Cables

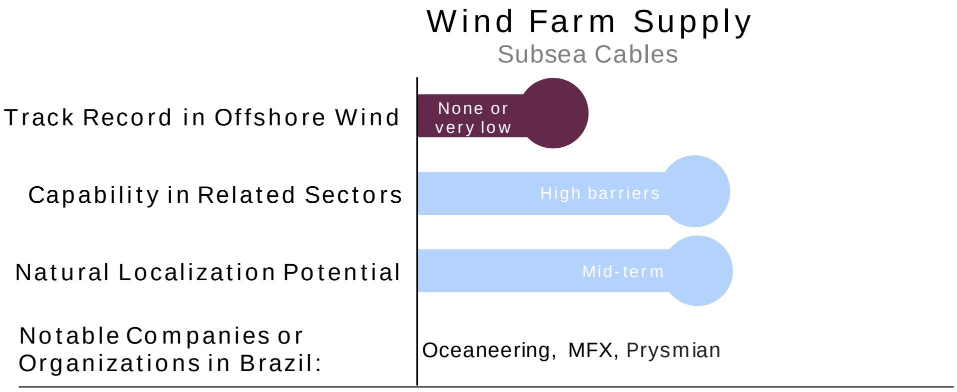


Figure 4-11: Summary of Criteria Score for Wind Farm Supply - Subsea Cables

Offshore wind subsea cables are usually split into two types: inter-array cables (IAC) and offshore export cables (OEC). The IAC connects the individual turbines to one-another and to the offshore substation, while the OEC connects the offshore substation to the shore. Subsea cables (for HVAC) are typically three cores set into a cross linked polyethylene base protected by steel wire armor. The cores can be copper or aluminum. Offshore wind IAC cables have recently increased from an industry standard of 33 kV to 66 kV, while export cables are often 132 kV or 220 kV.

There are currently a limited number of global suppliers and with the high barriers to entry, such as high upfront investment costs combined with complex technical capabilities, the global supply market is not expected to grow at the rate needed to meet coming demand. Related sectors, such as transmission and distribution, or oil and gas may react to high demand and relieve some of the high-voltage cable market pressure.

If Brazil experiences high offshore wind market growth, the local subsea cable industry in Brazil could be kicked-off in the above-listed related sectors. For example, Oceaneering has been present in Brazil since the 1970s and has an umbilical cable manufacturing facility in Niterói, Rio de Janeiro. Oceaneering's capabilities in the sectors O&G and renewables, for both subsea cables as well as cable accessories, such as cable protection systems (CPS) is globally known [42]. A second example, MFX, is a pioneer company in Brazil, manufacturing subsea umbilical cables in Salvador, Bahia, for companies such as

Schlumberger and Petrobras [43]. Umbilical cables compared to classic offshore wind cables are designed for a more dynamic environment, utilize more armor wiring, as well as contain low voltage cables, control cables and hydraulic lines. However, with certain adjustments, both companies may be able to supply subsea cables the Brazilian offshore wind market.

4.2.3.6 Offshore Substations

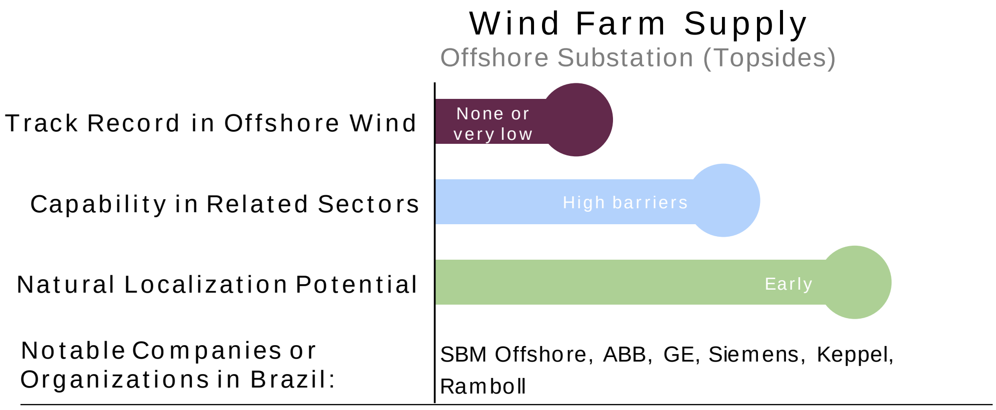


Figure 4-12: Summary of Criteria Score for Wind Farm Supply - Offshore Substation (Topside)

An offshore substation (OSS) can be viewed as the "heart" of an offshore wind farm. This offshore asset houses the electrical infrastructure required to step up the voltage from the turbines / inter-array cables to the export cables and onshore system. The OSS has two primary structures: the substructure, and the topside. The substructure is most often a pin-piled jacket type foundation or sometimes a monopile foundation. The topside can take a variety of forms, however is most often a tailor-made, multi-story platform which houses electrical equipment and auxiliary systems, such as transformers and switchgears. While the majority of this section will focus on fabrication of topsides, the following paragraph provides a brief summary of jacket supply.

The substructure of an offshore substation is dependent on the topside design and weight, as well as environmental conditions. Some offshore wind farms within closer distances to the shore are even opting not to include offshore substations, and rather route the inter-array cables directly to an onshore substation. The most common foundation type is a pin-piled jacket. The oil and gas industry, as well as Brazil's shipbuilding industry would be able to transition their steel structure capabilities to also support jacket fabrication in the offshore wind industry with moderate investments.

Figure 4-13: Offshore substation rendering of topside and jacket [73]

The topside of an OSS is a more complex asset. It is comprised of the platform structure, which includes indoor and outdoor decks across multiple levels, as well as the electrical equipment and auxiliary systems inside the platform.

Oftentimes the manufacturing locations for both the topside platform and the primary electrical components are not close to the offshore wind farm site. For example, European offshore wind farm topside structures are often fabricated in Asia. While Brazil does not have a track record in offshore wind OSS fabrication, Brazil has considerable experience in fabricating and integrating O&G offshore substations and floating production and offloading (FPSO) units. Many synergies can be found between the O&G and the offshore wind industries for offshore platforms, even though the former is generally smaller than the latter. SBM Offshore is one such company designing, supplying and integrating units on an FPSO vessel. Further global OSS fabricators, such as Keppel Offshore and Marine, also have waterfront facilities in Brazil which may be able to be adapted for the offshore wind substation business with assistance from their international headquarters. Structural designers, such as Ramboll, also already have offices in Brazil.

Brazil also hosts companies such as ABB, GE and Siemens who globally manufacture certain electrical components of a substation, though it is unclear if the electrical components required for an offshore wind substation are currently available in Brazil.

In summary, Brazil does not yet hold experience in manufacturing offshore wind substation topsides, however parallel industries, most notably oil and gas, perform similar projects on a smaller scale. With this experience, it is expected that certain areas of offshore substation fabrication could be an early localization area of the supply chain, though high investment barriers will still need to be overcome.

4.2.3.7 Onshore Electrical Infrastructure

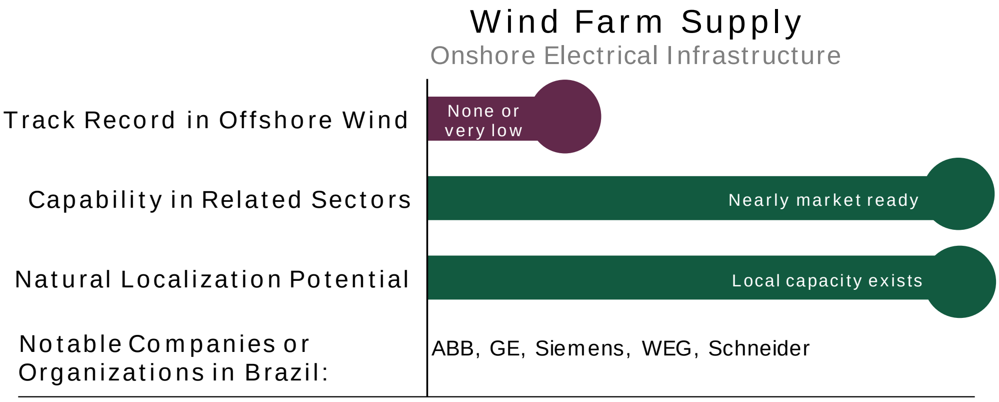


Figure 4-14: Summary of Criteria Score for Wind Farm Supply - Onshore Electrical Infrastructure

The onshore electrical infrastructure of an offshore wind farm receives the power from the offshore export cables ensures it can be distributed into the onshore transmission system or grid. These onshore substations are very similar to other power generating utilities already existing in Brazil. The primary electrical equipment includes switchgears and transformers, which can be easily found in the market and are not viewed as potential bottlenecks in the Brazil's offshore wind industry development.

Due to the capabilities of the Brazilian onshore wind industry, power generation from other renewables, as well as energy transmission and distribution sector (system integrators), the expertise covering the fabrication of onshore substations and the required electrical infrastructure is already present in Brazil. Notable companies are ABB, GE, Siemens, WEG and Schneider.

4.2.4 Wind Farm Installation

Offshore wind farm installation is perhaps the most specialized phase in an offshore wind farm's lifecycle. After manufacturing and pre-assembly, components are loaded onto specialized industry vessels which transport them to the offshore site and complete the installation process. Massive component sizes paired with precise installation requirements, all during harsh offshore sea and weather conditions make health, safety and environment a key factor in this phase. Each offshore component type differs in vessel requirements, offshore equipment requirements and workforce knowledge to achieve safe installation.

Globally, offshore wind's demand on the limited number of installation vessels is pushing developers to pursue optimized installation strategies, as well as early securing of vessel timeslots. While new-build vessels and retrofitted vessels are under construction, the vessel bottleneck is expected to continue in the offshore wind industry for the coming years.

4.2.4.1 Wind Turbine Generators

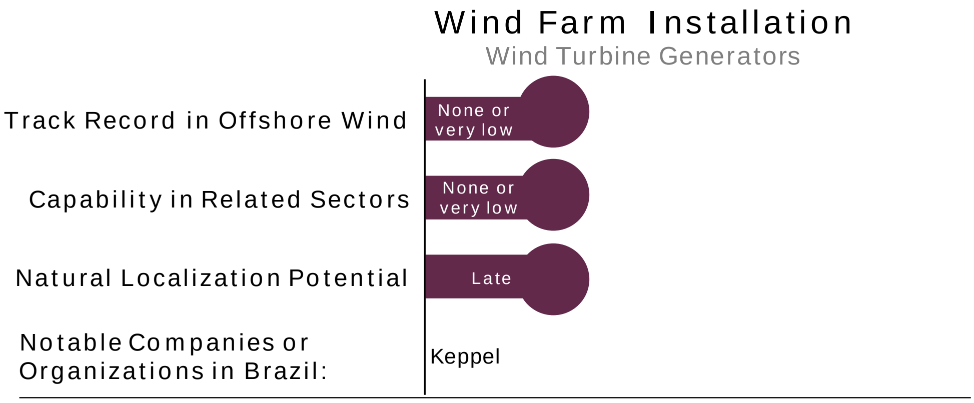


Figure 4-15: Summary of Criteria Score for Wind Farm Installation - Wind Turbine Generators

In general, the installation of a wind turbine generator (WTG) is performed utilizing an offshore wind specialized jack-up vessel (JUV), also known as a wind turbine installation vessel (WTIV). Globally, these vessels are in high demand, as only about 10 – 15 units are in operation, and only less than a handful are poised to handle growing turbine component sizes (sufficient hook height is a driving factor). As none of the global offshore wind transport and installation (T&I) companies are currently active in Brazil for offshore wind, a local track record for turbine installation (vessels or trained workforce) does not yet exist. It is currently expected that the global WTIV fleet will also supply the Brazilian offshore wind market for turbine installation, placing further demand on these assets.

Figure 4-16: Danish Cadeler's Jack-Up, Wind Fam Installation Vessel, Wind Osprey [72]

Further options would be local, new-build vessels, or perhaps retrofit of existing Brazilian vessels in related sectors, such as oil and gas. New-build vessels are very expensive and require specialized shipbuilding capacities. Nearly all offshore wind JUV are built in Asia, except when local legislation requirements and/or market volume is large enough to justify local construction (for example, in the United States or Japan). Oil and gas markets often include smaller JUV, or tripod JUV, however the deck space, hook heights, as well as lifting capacity of these vessels does not match the requirements for offshore wind and are often difficult to retrofit. Furthermore, the offshore wind requirements on the vessel’s jacking systems is completely different: while in oil and gas jacking is performed occasionally, the wind industry requires several, repetitive jacking operations during one season (almost on a daily basis). There has been a local push in recent years from Brazilian organizations and industries, such as Brazilian Association of Offshore Support Companies and Brazilian oil and gas companies, to expand the local fleet available to support offshore operations. This push for Brazilian flagged vessels has however not yet included JUV suitable for offshore wind. However, certain Brazilian companies with international roots may be able to transfer knowledge to the Brazilian market. Keppel is a Singapore headquartered company, also with two waterfront shipyards in Brazil, who holds experience in partial ownership of WTIV, as well as fabrication of certain WTIV structures such as leg components.

4.2.4.2 Foundations

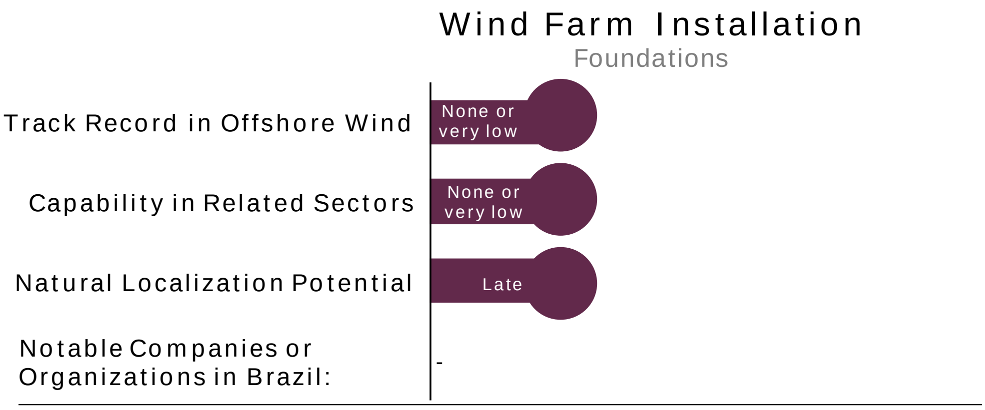


Figure 4-17: Summary of Criteria Score for Wind Farm Installation - Foundations

Foundation installation vessels in offshore wind are highly dependent on the foundation type. As this report considers monopile foundations, the same assumption will be made for the foundation installation vessel.

Monopiles and the subsequent transition piece (TP) are usually loaded directly onto the installation vessel at the marshalling harbor. The foundation installation vessel can be a jack-up vessel (JUV), similar to turbine installation, however, this depends on water depths and in recent years the offshore wind market has begun to trend towards floating foundation installation from heavy lift vessels (HLV). Certain projects are pursuing feeder installation options, either due to local legislation requirements or installation schedule optimizations, where the monopiles are loaded first onto feeder vessels or barges, and are brought to the offshore site, where the foundation installation vessel is located ready to install. Once offshore, the monopiles are one-by-one up-ended and piled into the seabed utilizing specialized equipment.

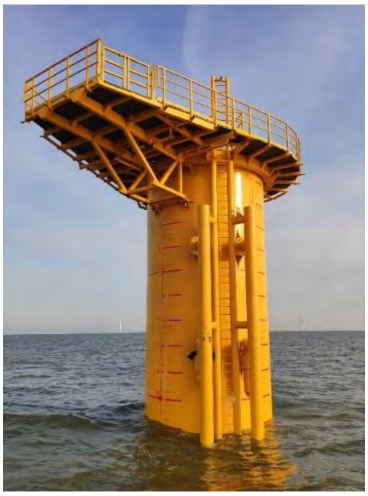


Figure 4-18: Exemplary installed monopile with transition piece [73]

As with turbine installation, JUV and HLV vessels are a high demand asset in offshore wind. Currently, none of the vessel owners are active in Brazil for offshore wind, meaning a local track record for foundation installation (vessels or trained workforce) does not yet exist. It is currently expected that the global fleet of offshore wind JUV or HLV will also supply the Brazilian offshore wind market for foundation installation, placing further demand on these assets.

With increasing turbine sizes, the foundation size correspondingly increases. Ceará's relatively (compared to Europe) shallow coastal waters may help to keep monopile tonnage lower than the average industry monopile size projections for 2030. Slightly smaller monopiles may have the advantage of utilizing installation vessels of the global fleet which other markets, with heavier foundations, can no longer utilize as strongly. However, it is expected that these vessels will also be kept busy through commissioning, potential decommissioning, and major component replacement campaigns. Further project-specific factors, such as soil conditions, also influence monopile size.

Opportunities for new-build vessels, or perhaps, retrofit of existing Brazilian vessels in related sectors, such as oil and gas do exist, however would require high demand and strong project pipelines.

4.2.4.3 Subsea Cables

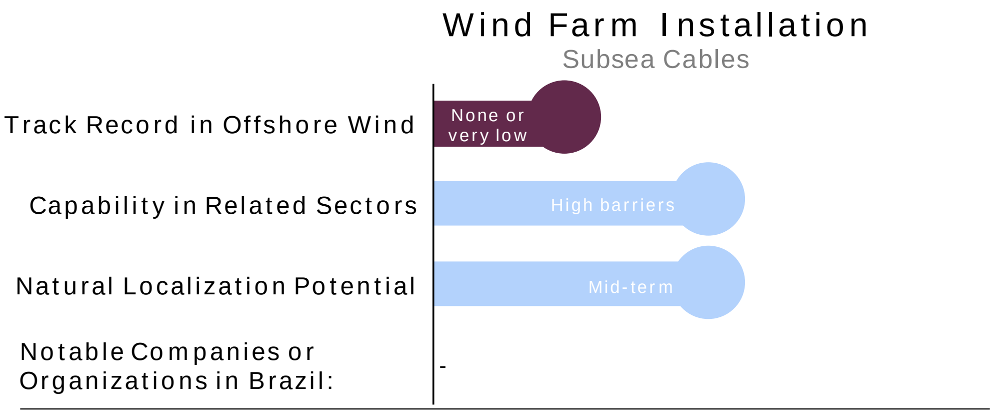


Figure 4-19: Summary of Criteria Score for Wind Farm Installation - Subsea Cables

The established offshore wind markets utilize specialized cable lay vessels (CLV) to install their export and inter-array subsea cables. These vessels focus on efficiency, operability in wider weather windows, often hybrid propulsion, and offer various options for laying and burial (for example, simultaneous laying and burial, post lay burial, etc.). Depending on water depths, cable diameters, and installation method required, projects often use multiple vessels to complete the various cable campaigns.

Figure 4-20: Danish NKT's Cable Lay Vessel, NKT Victoria [71]

While CLV are the industry preferred vessel assets for cable campaigns, the barrier for entry into subsea cable laying is far lower than turbine or foundation installation. While no offshore wind cable has been laid in Brazil or by a Brazilian company thus far, related sectors, such as oil and gas pipelines or subsea transmission lines, utilize comparable methodology. For example, shore landing of cables and pipeline are similar.

During the start of the offshore wind industry in Europe, offshore wind cables were installed by barges fitted with cable carousels as well as laying and/or burial equipment. The approach however was abandoned rather quickly as it poses far higher risks to all operations and generally a far less robust solution than a dedicated vessel. Conversions of vessels in related sectors, for example pipelaying vessels or barges, may sacrifice efficiency and sea-state operability, however, may provide a viable option in case of a globally saturated vessel market, as well as opportunities for local Brazilian supply chains. However, the global offshore wind market experiences developers pursuing best-in-class cable lay vessels and equipment for their projects whenever possible. A report released in 2021 by GCube Insurance found subsea cables as the most frequent and expensive losses within offshore wind farms from 2010 – 2020, with over 50% of total insurance claim spend [44]. Other sources are even referring to higher numbers. Forty-four percent of the cable claims could be attributed to contractor error in either transit or layout / burial [44]. Therefore, while less robust solutions are more technically feasible for cable laying than for turbine or foundation installation, the offshore wind industry in Brazil is expected to push for dedicated vessels and highly trained offshore wind workforce.

4.2.4.4 Offshore Substations

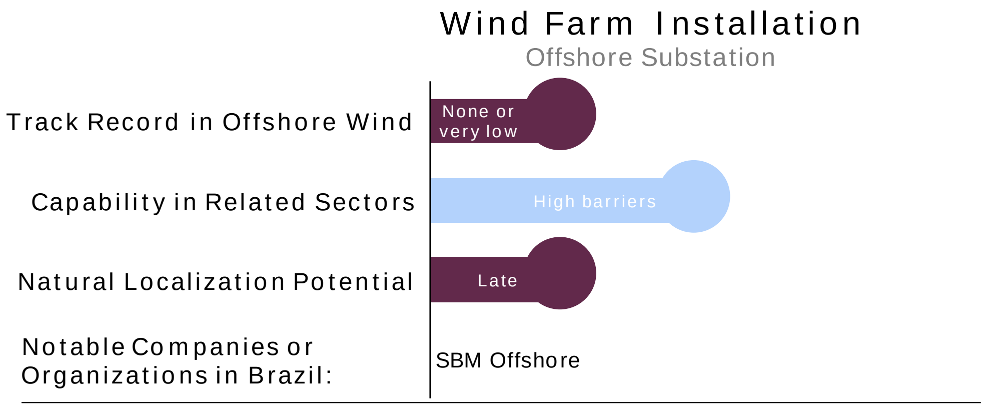


Figure 4-21: Summary of Criteria Score for Wind Farm Installation - Offshore Substation

Offshore Substation (OSS) installation (not including commissioning) is often a relatively brief campaign within a project's installation schedule, due to the installation involving only two primary components – the topside and the substructure. The installation process begins with the substructure, which is either brought on the installation vessel to the offshore site, or via barge. The installation vessel utilized is typically a heavy lift vessel (HLV) with sufficient crane capacity. The HLV lifts the substructure, typically a jacket type foundation, from its deck or off the barge and lowers it to the seabed before the piles are driven into place. If technically possible, the vessel installing the WTG foundations could also install the OSS foundation – therefore the remainder of this section will focus on topside installation.

The second phase is topside installation. As these platforms typically weigh over 2,000 mt, usually they are transported via barge to the offshore site where a heavy lift vessel lifts the topside onto the substructure. After installation of the topside, a large amount of time for completion works and offshore commissioning commences, requiring both service vessels (section 4.2.5.1) and installation support vessels (section 4.2.5.2).

The HLV utilized globally for offshore substation installation are often chartered from owners operating in both, the oil and gas sector as well as in offshore wind. Oil and gas topsides, when bottom-fixed, present similar installation methodologies to offshore wind substations. Brazil is well-known for its deep-water oil platforms, which are floating structures or floating production storage and offloading (FPSO) units. These floating installations are towed and moored to the seabed, without requiring a heavy lift vessel. However, during assembly of the FPSOs, sheerleg crane vessels are often used. One such shipyard utilizing sheerleg cranes for integrating FPSO modules for SBM Offshore is in Guanabara Bay, Rio de Janeiro. Sheerlegs used in yards are not necessarily sea-worthy and it would have to be assessed, if they were appropriate for deployment in offshore areas. In general, sheerleg vessels could be considered for OSS installation works, however, can be expected to come with stricter weather limitations for both transit to the offshore site and installation itself.

4.2.5 Offshore Logistics

Spanning both the installation as well as operational phases of an offshore wind farm's lifecycle, service vessels, as well as installation support vessels are required. These vessels provide a wide variety of offshore services, including but not limited to the offshore transfer of personnel, supply logistics and storage of certain components and materials, the overnight accommodation for personnel, and safety vessels for the offshore site. The vessels utilized for these tasks are diverse. Their purpose is to help optimize costs, as well as construction or maintenance schedules by decoupling certain tasks. A classic example is resupply of the installation vessel, without the installation vessel performing a port call. Decoupling such tasks allows the larger vessel asset to proceed with a continuous installation or maintenance campaign, thereby optimizing the schedule and vessel-related costs.

4.2.5.1 Service Vessels

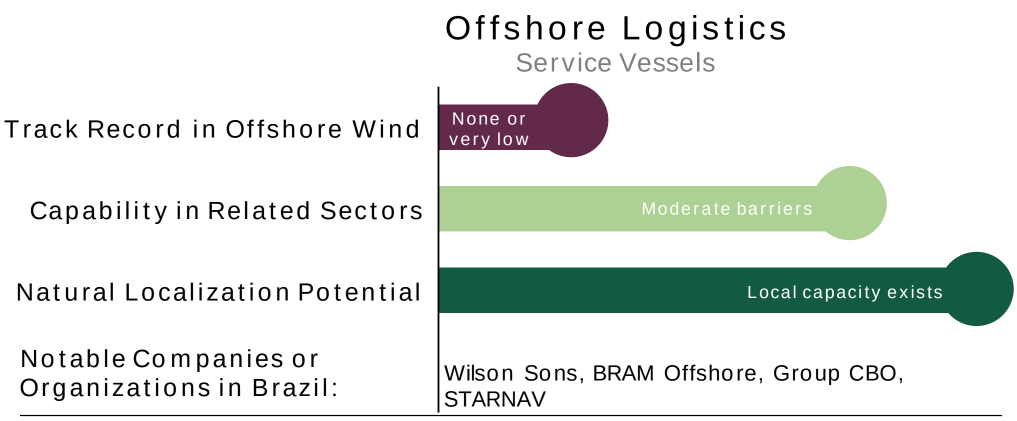


Figure 4-22: Summary of Criteria Score for Offshore Logistics - Service Vessels

Service vessels are utilized either during the installation phase, operations phase, or both phases. The variety of vessels which fall under the term 'service vessels' is diverse. Three common service vessel types are summarized in Table 4-6.

Within the past decade, Brazil's oil and gas industry began a push to increase the number of Brazilian-built and/or Brazilian flagged service vessels utilized in the O&G industry, in part through the program Decennial Energy expansion Plan 2029. The campaign was quite successful, with January 2019 boasting 367 offshore support vessels in Brazilian waters, of which 328 were Brazilian flagged, up from 247 Brazilian flagged vessels in 2015 [45] [46]. While many of these 300+ support vessels apply to the following section (Installation Support Vessels – Section 4.2.5.2), an estimated 94 were classified as either small supply / support vessels, or fast supply / fast crew carriers [45]. These vessels are not built specifically for the offshore wind industry, as they are in many of the established offshore wind markets. For example, crew transfer vessels (CTVs) as described in Table 4-6 are not currently in use in Brazilian oil and gas.

The existing fleet of Brazilian offshore service vessels are operated by a variety of companies, including Wilson Sons, BRAM Offshore, Group CBO (Companhia Brasileira de Offshore), and STARNAV. The vessel fleets of each were not examined in detail in this report to find their potential applicability for offshore wind. The use of these local vessels may sacrifice certain offshore wind specific characteristics, such as higher weather window operability, however, allow for further support of the local offshore service vessel market. Shipyards in Brazil are also capable of retrofitting existing vessels, for example upgrading supply vessels by adding walk-to-work (W2W) systems, or newbuilding offshore wind specialized CTVs. However, for the operations phase, dedicated SOVs were new built, since a purpose build design is usually more effective and efficient.

Table 4-6: Frequently seen offshore wind service vessels

Vessel	Description	Example Photos
Crew Transfer Vessel (CTV)	Transport of personnel, and occasionally equipment such as smaller spare parts and tools, from the onshore base to the offshore site. CTVs are used both during the installation as well as operations phases. These vessels are typically used for shorter day journeys to site, with shorter transit durations.	 Example CTV, photo from World Marine Offshore [47]
Service Operation Vessel (SOV)	Longer duration accommodation of personnel offshore, often for up to two weeks. SOVs are used both during the installation phase, as well as larger operations campaigns. SOVs are often fitted with small cranes for equipment deliveries, workshops, as well as walk-to-work (W2W) systems to ensure safe transfer of personnel and smaller material to the offshore assets. Depending on the (access) strategy they may be equipped with a helipad as well.	 Example SOV, photo from Esvagt [48]
Guard Vessels	Monitoring and security of the offshore site during installation, both on behalf of the developer to avoid accidental damage to offshore assets or stop of work caused by other maritime users, and also for other maritime users to ensure they know construction is underway. The use and radius (e.g. entire offshore site, vs. direct construction works) of guard vessels is country / permit dependent. Certain countries require their use, while others suggest it.	 Example guard vessel, photo from James Fischer [49]

4.2.5.2 Installation Support Vessels

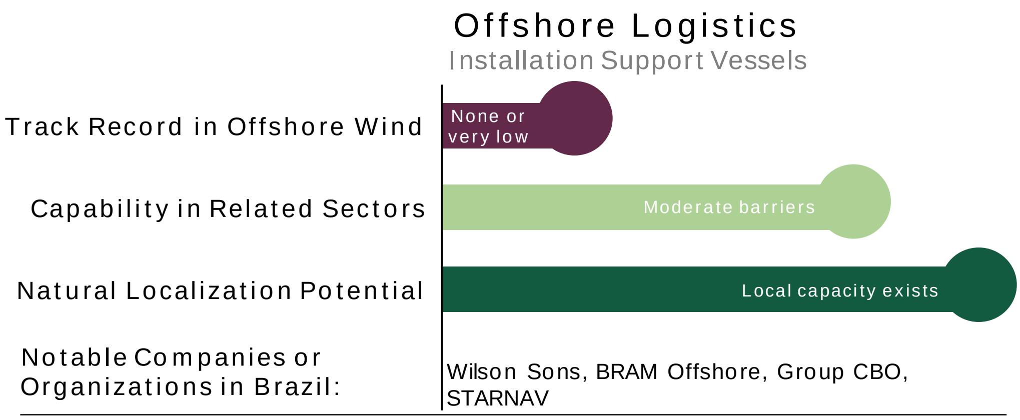


Figure 4-23: Summary of Criteria Score for Offshore Logistics - Installation Support Vessels

Installation support vessels span a wide variety of vessel types, a few of which are outlined in Table 4-7. Their primary purpose is to supply the larger vessel assets offshore with the components, materials and equipment needed to keep their offshore campaigns continuous, and therefore optimize project schedule and costs. Which installation support vessels are utilized on a project is highly dependent on the project's transport and installation (T&I) strategy, including but not limited to the design, various fabrication locations, distance to the offshore site and installation methodologies (e.g., installation vessel port calls or feedering).

The Brazilian oil and gas sector also utilizes many similar vessel types to the offshore wind industry. Within the past decade, Brazilian O&G began a push to increase the number of Brazilian-built and/or Brazilian flagged support vessels in their industry, in part through the program Decennial Energy expansion Plan 2029 as mentioned in the previous section. The campaign was quite successful, with January 2019 boasting 367 offshore support vessels in Brazilian waters, of which 328 were Brazilian flagged, up from 247 Brazilian flagged vessels in 2015 [45] [46]. In 2019, an estimated 178 vessels were either platform supply vessels (PSV) or oil spill response vessels (OSRV), 46 were anchor handling tug supply vessels (AHTS), and 11 remotely operated vehicle (ROV) support vessels [45]. Brazil oil and gas also utilizes barges. The existing fleet of Brazilian offshore support vessels are operated by a variety of companies, including Wilson Sons, BRAM Offshore, Group CBO (Companhia Brasileira de Offshore), and STARNAV. Equinor, one of the global offshore wind developers, has already contracted CBO for PSVs in Brazil within their oil and gas works [50].

The basic attributes of these more specific O&G support vessels are well suited to the wind sector. Converting and redeploying these oil and gas vessel are a fair possibility as the offshore wind market grows and the demand rises. Shipyards in Brazil are capable of such retrofit projects or newbuilding offshore wind specialized installation support vessels.

Table 4-7: Frequently seen offshore wind installation support vessels

Vessel	Description	Example Photos
Platform Supply Vessel (PSV)	Transport of supplies and large equipment offshore, as well as personnel. PSVs are utilized both in installation and larger maintenance campaigns. PSVs are sometimes also referred to as Offshore Supply Vessels (OSV) and are often retrofitted from the oil and gas industry to meet the needs of the offshore wind market.	 Example platform supply vessel from Rem [51]
Anchor Handling Tug Supply (AHTS) and Cargo Barges	Either used for transport of components from manufacturing yard to marshalling port for shorter distances, or for feeding of components (e.g., offshore substation topsides) from fabrication yards or marshalling ports to the installation vessel offshore. The use of tugs and barges during transport and installation (T&I) campaigns is highly dependent on the T&I strategy of the project.	 Example tug and barge setup, photo from Royal Wagenborg [52]
Heavy Transport Vessel	Large component, far distance transport, usually from manufacturing yard to marshalling port. Heavy transport vessels (HTVs) focus on the load they are able to transport, speed with which the transport can occur and lowest fuel consumption. The use of HTVs during T&I campaigns is highly dependent on the supply chain setup as well as T&I strategy.	 Example heavy transport vessel, photo from Seaway 7 [53]

4.2.6 Operation and Maintenance

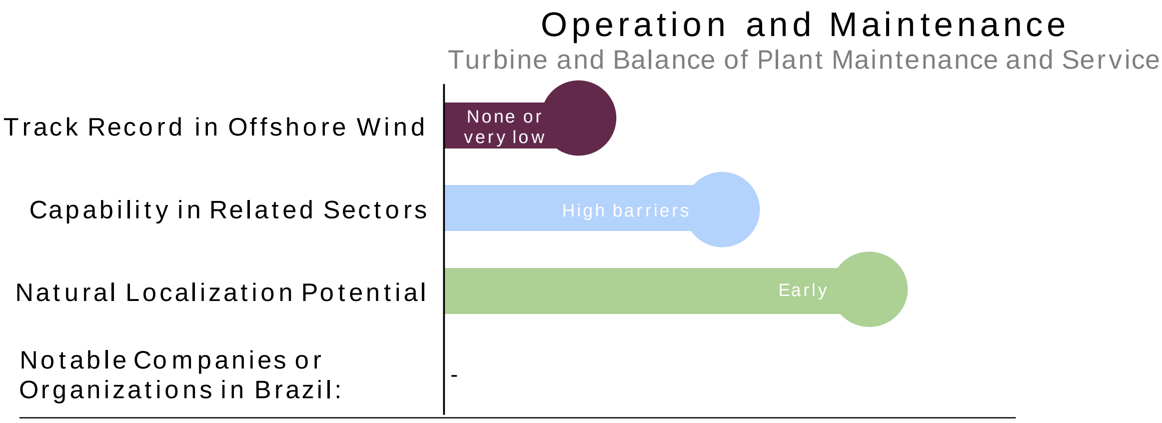


Figure 4-24: Summary of Criteria Score for Operation and Maintenance - Turbine and Balance of Plant Maintenance Service

Operation and maintenance (O&M) is the longest phase of an offshore wind farm’s lifecycle at 25+ years. O&M is typically managed from an onshore base, which usually includes planning offices for inspections, maintenance and repair of components, marine coordination activities, as well as spare parts and consumables storage. Due to frequent travel of technicians to the offshore site, these onshore bases are usually located in a port close to the offshore wind farm site. On occasion, large maintenance campaigns will be required, for example replacement of blades. These campaigns require larger vessels, which may require a different port.

Wind turbine generator (WTG) maintenance and service in offshore wind is typically completed by the WTG original equipment manufacturer (OEM), for at least the first five years of operation. Many wind farms then choose to extend the contract, as turbine manufacturers have specialized technicians for their products, as well as access to the spare parts and consumables required. Onshore wind technicians in Brazil have many of the necessary technical skills for offshore turbine maintenance, however are not accustomed to the challenges a marine environment introduces. Top onshore wind turbine manufacturers in Brazil include Vestas, Siemens Gamesa, GE Renewable Energy and Acciona Windpower. Offshore wind technicians must be well trained in health, safety and environmental risks of working offshore, an aspect currently not covered in onshore wind. The Danish organization Global Wind Organization (GWO) is the market leader in setting the offshore wind’s industry standards for safety trainings. Due to both regular and quick reactions required in O&M activities, most of the WTG O&M services are expected to be provided locally. It is expected that offshore turbine maintenance workforce and trainings will build up relatively naturally and quickly once a pipeline of offshore wind projects is committed.

Balance of plant (BoP) maintenance and service refers to all offshore components which are not the turbine. This includes foundations, offshore substation and cables. In offshore wind these components are often maintained through a mixture of the developer’s internal teams, as well as subcontracted specialists.

Foundation O&M activities are generally limited to scheduled inspections, as failures are quite rare. The offshore substation is a combination of structural steel O&M activities, similar to the WTG foundations, as well as O&M activities for electrical equipment and auxiliary systems in the topside. As the offshore substation is a critical element for transferring power to shore, regular maintenance is required to ensure continuous operations.

In recent years, O&M for subsea cables as well as their cable protection systems (CPS) have received increased attention in the European offshore wind industry. Cable damages due to abrasion, insufficient scour protection and other mechanical damage to the cable have caused large replace and / or repair campaigns. Due to the costly loss cable damages can bring to a wind farm, O&M for cables, including regular monitoring and burial inspections, is critical element of BoP O&M.

BoP maintenance and service is expected to have a higher learning curve for the Brazilian market than turbine maintenance and service, however it is also expected to naturally localize quite quickly due to frequency of tasks and quick response times required. Certain skills and methodologies already exist in the local market, such as underwater inspections and ROV operations from oil and gas. These skills can apply to the offshore wind industry relatively easily. For the remainder, global partnerships in the offshore wind market will assist in quickly transferring knowledge to the Brazilian local market.

4.3 Conclusions

Table 4-8 summarizes the results of the supply chain opportunities and gap analysis. For further explanation of each of the rated criteria in the table below, please refer to Section 4.1. Stakeholder engagement throughout drafting this report indicated strong local and global interest in developing the offshore wind industry in Brazil, however unclear regulatory framework is currently hindering even the earliest investments in supply chain development. Nevertheless, compared to other global offshore wind markets, the potential Brazil holds for high-volume development along its coasts is viewed as a major opportunity to the global offshore wind industry. A key in ensuring the local supply chain's success, once initiated, will be steady development and ensuring suppliers can rely on a continuous pipeline of projects.

Table 4-8: Summary of supply chain opportunities and gaps analysis results

Phase	Category	Offshore Wind Track Record	Capability in Relevant Sectors	Natural Localization Potential
Research and Development	Government Initiatives, Non-profits, Private Industry	Low	Moderate barriers	Early
Project Management	Service Providers	Low	Nearly market ready	Early
	Offshore Wind Developers	None or very low	Moderate barriers	Early
Wind Farm Supply	Nacelles and hubs	None or very low	High barriers	Late
	Blades	None or very low	Moderate barriers	Mid-Term
	Tower	None or very low	Moderate barriers	Mid-Term
	Foundations (Monopile)	None or very low	High barriers	Mid-Term
	Subsea Cables	None or very low	High barriers	Mid-Term
	Offshore Substation	None or very low	High barriers	Early
	Onshore Infrastructure	None or very low	Nearly market ready	Local capacity exists
Wind Farm Installation	Turbine	None or very low	None or very low	Late
	Foundation	None or very low	None or very low	Late
	Subsea Cable	None or very low	High barriers	Mid-Term
	Offshore Substation	None or very low	High barriers	Late
Offshore Logistics	Service Vessels	None or very low	Moderate barriers	Local capacity exists
	Installation Support Vessels	None or very low	Moderate barriers	Local capacity exists
Operations and Maintenance	Turbine and Balance of Plant Maintenance and Service	None or very low	High barriers	Early

The largest opportunities identified in the Brazilian supply chain are where related sectors with skilled workforce also face low to moderate barriers of entry into the offshore wind market, such as the supply of blades, towers and onshore electrical infrastructure, as well as offshore logistics vessels. Such opportunities have either lower investment barriers, or lower further training requirements for existing supply chains to expand into offshore wind.

The categories of research and development and project management are expected to localize early due to lower barriers and high incentives. Both areas can profit easily from knowledge sharing and capacity building with experienced partners.

In the supply of components, turbine blades, turbine towers and onshore electrical infrastructure were found to have the lowest potential barriers, leading to an estimated mid-term localization (3 – 10 GW). However individual companies and institutes looking to invest or expand into offshore wind in these areas will need to weigh many factors, including the requirements of waterfront access facilities, investments in new equipment and balancing offshore wind's project-based and therefore intermittent business with their other business units.

In terms of vessels, the largest opportunity was identified in Brazil's offshore logistic vessels fleet and their potential to support the offshore wind industry. Their utilization may depend on developers' transport and installation strategies, as well as operation and maintenance plans.

A noticeable gap in the analysis is generally a track record in offshore wind from Brazilian companies, however this is expected in an emerging market. It is quite rare that an emerging market holds offshore wind experience before the industry is also local. Partnerships with global offshore wind players, as also explored further in Section 5 Opportunities for Danish Companies, can help to quickly close experience gaps through efficient knowledge sharing.

Additionally challenging to localize will be the supply of certain components, which are often in the global offshore wind market supplied from few, select locations and manufacturers, such as turbine nacelles and hubs. For these components, high barriers are expected, requiring an estimated pipeline of at least 10 GW of projects before a local supply chain would meaningfully develop. Monopile foundations and subsea cables also show high barriers for entry into Brazil's local supply chain. The high investments required for new waterfront facilities, larger or new equipment and training of workforce, are expected to significantly slow the build-up of a local supply chain.

For vessels, an identified gap is the turbine and foundation installation vessels. This gap is a global offshore wind identified bottleneck and therefore not specific to Brazil. Multiple new-build vessels are announced, however it is still expected developers will need to secure vessel contracts earlier than in the past, to ensure vessels are available to install their offshore wind farms.

In summary, Brazil's offshore wind supply chain holds both opportunities and challenges. The potential scale of Brazil's offshore wind market is keeping the global industry engaged, however a lack of regulatory framework is hindering even early supply chain investments. Once the next steps are outlined for competitive auctions or other seabed lease allocations, developers will be required to begin exploring build-up of the local supply chain. The strong Brazilian onshore wind and oil and gas sectors lend many promising synergies to a future offshore wind market, however ensuring committed and steady volumes of offshore wind projects to future suppliers will be necessary before local companies make the necessary investments to supply offshore wind. Finally, the global offshore wind market holds many insights and lessons learned in developing supply chains. Brazil should continue exploring and utilizing this global knowledge resource through private and public partnerships and joint ventures, which are further discussed in the next Section 5.

5 Opportunities for Danish Companies

As the offshore wind market of Brazil and Ceará develops it will be crucial to gather established markets' experience, insights and knowledge through public and private partnerships, as well as attract international investment. Denmark, as a pioneer in offshore wind and a top-ranked knowledge management and dissemination expert, is one such established market. There are successful Danish companies in nearly every category discussed in the supply chain analysis (Section 4), with much to offer regarding offshore wind experience and services.

Denmark is both the birthplace of offshore wind and a country recognized in the offshore wind industry for a focus on knowledge organization and sharing. The companies, government and public institutes of Denmark have proven repeatedly that they are interested in developing the offshore wind industry as a whole, through both research and development, as well as applying their lessons learned and knowledge to new markets. One of many examples is the turbine test site Østerild, where the Technical University of Denmark, the local Thisted Municipality, the architecture and planning association Realdania, Wind Denmark, the Danish Nature Agency and the major, global turbine manufactures cooperate to test and study the newest turbine models, as well as provide a public visitors center to further general education on wind energy.

Both public and private institutes of Denmark have shown strong interest in Brazil. This report itself and the INNOWIND project are the result of wind energy innovation collaboration between the two countries. The competencies of Danish companies can help to strengthen the Brazilian offshore wind industry, as well as supply chain, through international investment, export of technology and services to Brazil, as well as accelerating development through public and private partnerships.

The level of involvement from international players, such as Danish companies, is highly dependent on the local supply chain's capabilities. Typically, emerging markets see high involvement of international companies in early stages of a country's offshore wind project pipeline (< 3 GW). The local supply chain is typically just beginning to establish, both with technology, facilities and skilled workforce. At this stage of market development, Danish companies are often directly providing goods or services to the wind farm, which enables the developer to benefit from the lower pricing of established offshore wind players and avoid putting overly high pressure on the local supply chain. Mid-term, the international investment begins to transition into partnerships and joint ventures with local suppliers. These partnerships allow the emerging market to continue to develop at appropriate speed, while gathering good industry practices from experienced markets. Finally, with a long-term, high-volume pipeline (10+ GW) joint ventures and partnerships between local and Danish companies are well-established and functioning; the local supply chain now has the technology, experience and workforce to continue development and maintain their offshore wind market. The Brazilian partner still continuously benefits from the knowledge transfer of the Danish partner company. Very successful partnerships may go on to export to further markets together.

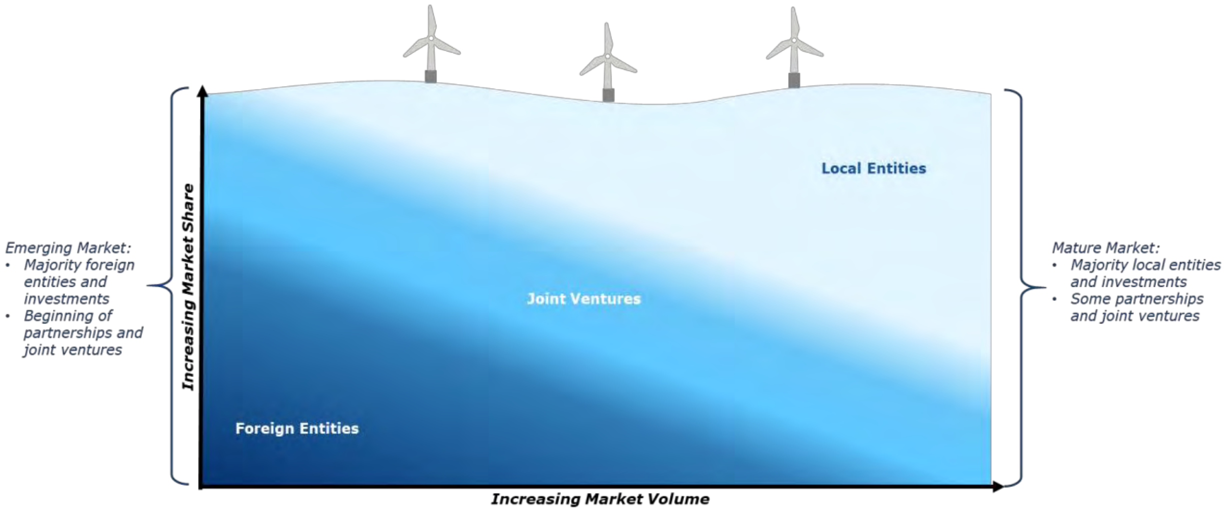


Figure 5-1: Transfer of foreign supply and investment to local supply and investment with increase in market volume

International investment for an emerging offshore wind market is key, as local financing markets are typically not able to support a steady offshore wind project pipeline [5]. Interest in investment has already been demonstrated through Danish companies, such as Copenhagen Offshore Partners (COP), actively exploring offshore wind project development in Brazil. Bankable frameworks, such as stable revenue support and environmental and social safeguards, will be seen as a signal from Brazil to attract foreign investment.

Danish technology and service providers serve nearly every package of the offshore wind industry. Table 5-1 lists the phases and categories of an offshore wind farm, as used in the supply chain analysis (Section 4), now supplemented with opportunities for Danish companies, as well as a high-level, not-exhaustive summary of key, Danish offshore wind industry players. Small and medium sized Danish companies also have plenty to offer emerging markets entering offshore wind. Their capabilities and niche expertise, as well as oftentimes more agile management processes, would provide Brazilian companies and organizations with strong partnerships.

Table 5-1: Summary of opportunities for Danish Suppliers in the Brazilian offshore wind market

Phase	Category	Opportunities for Danish Companies
Research and Development	Government Initiatives, Non-profits and Private Industry	Brazil has kicked off R&D initiatives, such as the Green Hydrogen Hub, however does not yet have a thriving R&D market for offshore wind aimed at furthering the industry as a whole and adding value to Brazil's market [18]. This is expected to develop in the early in the market's establishment. Danish companies and institutes continue to be at the leading-edge for research and development in offshore wind, examples are programs from Danish Energy Agency, Energy Cluster Denmark, Technical University of Denmark, Megavind, Danish Technological Institute, LORC, DTU Test Center Østerild and DTU Risø.

Project Management	Service Providers	The support of service providers in offshore wind farm development is crucial. Though expected to be relatively early established locally, it is also expected this is made possible through international knowledge sharing and investment in, for example, offices in Brazil. Danish designers, engineers, project managers and consultants such as COWI, K2 Management, NIRAS and Ramboll have extensive offshore wind experience to share and are at least partially already active in Brazil.
	Offshore Wind Developers	Offshore wind developers are some of the key investors in an offshore wind industry. Emerging markets often see international developers partnering with local companies to share experience and capital. With no offshore wind farms existent yet in Brazil, there is a lack of experience in the Brazilian market. Denmark is home to the largest offshore wind developer globally, Ørsted, as well as other well-known developers such as Copenhagen Offshore Partners (COP), who are already active in Brazil, as well as European Energy.
Wind Farm Supply	Turbines Including: • Nacelles and hubs • Blades • Tower	Though Brazil has a strong onshore wind turbine industry, international experience and export will be needed to help scale up to offshore wind dimensions. Nacelles, hub and blades are only expected to transition to local supply in the mid-to-long term, while towers may experience quicker localization. Denmark is home to one of the three key turbine suppliers in offshore wind, Vestas, who is also actively engaged in the Brazilian market, as well as companies such as LM Wind Power a multinational blade fabricator, Welcon the tower fabricator, as well as system and component suppliers like KK Wind Solutions, Jupiter Bach and Mita-Teknik.
	Foundation (Monopiles)	Brazil does not currently fabricate any monopile foundations, leaving a knowledge gap which will be vital to fill for Brazil's offshore wind market to begin. Brazil does have onshore wind tower manufacturing, steel structure fabrication from shipbuilding and oil and gas, as well as raw materials, however has not yet translated this for monopile fabrication and is only expected to become local supply in the mid-term. Bladt Industries is an example of a Danish company, who is a key player in the industry for fabrication of both monopiles and transition pieces.
	Subsea Cables	Subsea cable manufacturing in Brazil has until now been focused primarily on the oil and gas industry.

		Experience, technology and most likely export will be required from international companies for the early-to-mid-term of the Brazilian market. Danish company NKT Group is a leading cable manufacturer in offshore wind with their own installation vessel, the NKT Victoria.
	Offshore Substation	Brazilian offshore wind substations are expected to benefit from the local oil and gas, FPSO and shipbuilding industries. In the early-to-mid-term the supply is expected to be local, however as OSS are custom-built, there is a large knowledge transfer opportunities into the Brazilian market. Denmark's many offshore wind farms (developers and service providers) have undergone the OSS design and fabrication process numerous times. Notable companies include jacket fabricator Bladt, OSS engineer Ramboll and OSS engineer, construction and maintenance provider Semco Maritime.
	Onshore Infrastructure	The experience for onshore electrical infrastructure is already built up in Brazil through other utilities and renewables. International experience may help tailor these competencies for the offshore wind market, however strong international engagement is not expected.
Wind Farm Installation	Turbine	Turbine installation capabilities are not currently represented in the local Brazilian supply chain and are expected to localize quite late. International vessels and service providers will be required for safe and proper installation of turbine components in Brazil. Danish companies have a long history in transport and installation (T&I). The Danish company, Cadeler, operates two jack-up vessels with a robust history of installing turbines. Both of Cadeler's vessels currently sail under the flag of Denmark. Cadeler is also constructing a new generation of vessels for 15MW + turbines. Another well-known T&I player, A2Sea, now part of DEME Group, was headquartered in Denmark. Furthermore, Danish companies, such as K2 Management and Ramboll have extensive experience in managing T&I of components, and Danish companies such as Blue Water Shipping hold extensive experience in offshore logistics. The GWO, the industry standard organization for offshore health and safety are also Danish.
	Foundation	Foundation installation capabilities are not currently represented in the local Brazilian supply chain and are expected to localize quite late. International vessels and service providers will be required for

		safe and proper installation of foundation components in Brazil. Danish companies have a long history in transport and installation (T&I). The Danish company, Cadeler, operates two jack-up vessels with a robust track record of installing monopiles. Both of Cadeler's vessels currently sail under the flag of Denmark. Cadeler is also constructing a new vessel capable of both foundation and turbine installation. Another well-known T&I player, A2Sea, now part of DEME Group, was headquartered in Denmark. Furthermore, Danish companies, such as K2 Management and Ramboll have extensive experience in managing T&I of components, and Danish companies such as Blue Water Shipping hold extensive experience in offshore logistics. The GWO, the industry standard organization for offshore health and safety are also Danish.
	Subsea Cables	Subsea cable installation is expected to localize quicker than installation of other components, already in the mid-term, due to lower investment and technology barriers, as well as related industries of pipelines and transmission line laying. Danish cable manufacturer and installer, NKT, own and operate the cable lay vessel NKT Victoria. Furthermore, Danish companies, such as K2 Management and Ramboll have extensive experience in managing T&I of components, and Danish companies such as Blue Water Shipping hold extensive experience in offshore logistics. The GWO, the industry standard organization for offshore health and safety are also Danish.
	Offshore Substation	Offshore Substation (OSS) installation in Brazil may be supported by the existing oil and gas industry, for example sheerleg cranes. However, OSS installation is generally expected to localize quite late. International experience, vessels and service providers will be required for safe and proper installation of OSS components in Brazil.

		Danish companies have a long history in transport and installation. Cadeler's vessels and crews have a track record of performing OSS accommodation and commissioning works for offshore substations. Both of Cadeler's vessels currently sail under the flag of Denmark. Additionally, A2Sea, now part of DEME Group, was headquartered in Denmark. Furthermore, Danish companies, such as K2 Management and Ramboll have extensive experience in managing T&I of components, and Danish companies such as Blue Water Shipping hold extensive experience in offshore logistics. The GWO, the industry standard organization for offshore health and safety are also Danish
Offshore Logistics	Service Vessels	In thanks to the strong maritime industries in Brazil, many service vessels are already available in the Brazilian market. International experience may help tailor the vessel services or provide specialized service vessels for the offshore wind market, however strong international engagement is not expected. The Danish companies of ESVAGT and World Marine Offshore own and operate offshore wind service vessels.
	Installation Support Vessels	Same as "service vessels" above
Operations and Maintenance	Turbine and Balance of Plant Maintenance and Service	While operation and maintenance is foreseen to have early adaption into Brazil's local supply chain, this is due to the necessity of on-site, frequent engagement with the wind farm itself, rather than existing capabilities in Brazil's supply chain. O&M would greatly benefit from international investment and knowledge sharing. Danish companies hold long track records in operating and maintaining offshore wind farms, both developers as well as service providers and consultants. Danish service providers include Ziton, who supplies O&M services both for developers as well as turbine manufacturers, as well as FairWind, who supply pre-assembly, installation and maintenance services for turbines. Furthermore, multiple Danish ports hold extensive experience in transitioning to serve O&M operations for offshore wind farms.


Photo: Port of Pecém

6 Port Infrastructure Assessment

This section of the report analyzes the readiness and adequacy of port infrastructure to serve offshore wind farms in Ceará. The available relevant ports shortlisted for potential offshore wind involvement are introduced and their current capabilities are shown together with a list of required upgrades that would be needed for them to serve the offshore wind market.

6.1 Scope

Port infrastructure is a key enabler of offshore wind, serving several roles over the life cycle of a wind farm, as presented below in Table 6-1:

Table 6-1: Role of ports in offshore wind farms per life cycle phase

Wind Farm Lifecycle Phase	Role of Ports
Project Development	During the development of a wind farm, the required port infrastructure is light as they support survey vessels, but the ports do not necessarily need to be close to the wind farm area for these activities.
Manufacturing	As wind farm components such as foundations, cabling and turbines start to be manufactured, the importance of available port infrastructure increases dramatically. For the current and future sizes of turbines, these manufacturing facilities are located together at a private or shared port space, because the components are too large to be transported over land. From the manufacturing ports, the components are shipped to the installation port.
Installation	In this phase, there are the highest requirements placed on the port, both in terms of technical requirements and proximity to the wind farm. Considering the high day-rates of installation vessels, the proximity to wind farm is economically necessary.
Operation and Maintenance (O&M)	For the regular operations and maintenance of a wind farm, ports are needed to permanently host crew transfer vessels (or potentially service operation vessels) over the 25+ year life of the offshore wind farm, as well as to store spare parts. If a major repair is needed at the wind farm, larger vessels are often needed to perform that repair, which may have higher port requirements.
Decommissioning	Ports are needed to host the vessels that will break down and recycle the wind farm. Many developers plan simply to reverse the installation process steps, using similar vessels, though alternative concepts are also being considered.

The focus of this report will be on port requirements for the installation and O&M phases. Port-related activities for these phases are essential to an offshore wind farm and a lack of these facilities will prevent wind farms from being constructed. These ports are generally the first movers on offshore wind.

Ports in these phases must also be near to the wind farm, which is not the case, for example for manufacturing activities and ports. As many components are manufactured in separate locations and all shipped to the installation port for storage and staging, these facilities can be much further away from the wind farm and still be economically viable if they have waterfront manufacturing space. The Scottish Neart na Gaoithe offshore wind farm, for example, famously had its jacket foundations fabricated in Indonesia and shipped to Scotland [54]. It is common to have foundations, cables, nacelles, blades and towers manufactured in separate factories and be delivered separately to the installation port. As there are so many economically feasible constellations for manufacturing ports, manufacturers often wait to see an established pipeline before making the investment to establish new premises. This leads manufacturers to typically be second movers.

The decommissioning phase is not yet considered relevant for Brazil, as this would take place, at the earliest, in about three decades. In principle, any port which can serve the installation phase would also be able to support decommissioning, though by the time decommissioning is needed alternative solutions with lower port requirements may have been developed.

This analysis concentrates on the wind farm sites in Ceará, but this does not mean the port infrastructure serving these wind farms necessarily needs to be in Ceará. Installation and O&M ports must be relatively close to the wind farm, so this analysis also considers the neighboring states of Piaui and Rio Grande do Norte.

6.2 Methodology

This assessment does not represent an in-depth study of the technical feasibility of building or upgrading any port infrastructure, but rather aims to provide a high-level overview of port capabilities.

The port assessment has been performed in the following steps:

1. Define a reference windfarm including both project and technical details, as given in Section 3
2. Evaluate associated port requirements
3. Screen and evaluate ports according to the benchmark.

Following the assessment of relevant ports, a qualitative case study was performed for the Port of Pecém. The aim of this case study is to demonstrate, with a concrete example, how current infrastructure could be used for offshore wind and which additional infrastructure would be necessary. The Port of Pecém was chosen for this case study because the port's operators have expressed significant interest in offshore wind as well as the port's ideal location to serve most of Ceará's wind farms.

During this study Ramboll used public data as well as held direct stakeholder engagement discussions with some ports. The Port Master Plans were consulted to identify their infrastructure and operation characteristics for the analysis.

Based on characteristics of the reference wind farm and best industry practice, key benchmark parameters were defined for both installation and O&M ports, in sections 6.3.1 and 6.5.1, respectively. These parameters consider that wind farm components are constantly increasing in size and weight and port operation requirements are increasing along with them. The chosen parameters serve the purposes of port selection, and the identification of potential upgrades. The parameters are separated into "acceptable" and "recommended" values.

The "acceptable" values are considered as the port requirements which would enable the development of a windfarm but have significant impact on the transport and installation (T&I) strategy. The T&I strategy would have to limit the variety and number of installation and transportation vessels that can be mobilized, leading to a negative impact on the overall windfarm construction duration. The "recommended" values are selected for ports aiming to be windfarm installation hubs which are used as logistic harbors for consecutive projects. The parameters would enable a large variety of T&I set-ups considering a typical wind farm and its installation. While other transport and installation concepts are available (such as feeder barges), this report considers the most common setup using wind turbine installation vessels (WTIV).

The benchmarks should be seen as high-level guidelines, rather than a rigid set of rules. For any individual port and specific wind farm project, a detailed analysis of T&I concepts and port usage should be performed. Furthermore, the benchmarks shall be considered as reflections of Ramboll's experience, rather than as an outline of foundation or turbine manufacturer specifications. Oftentimes emerging markets must initiate the flow of projects by utilizing less-than-ideal port set-ups before investments can be secured for moderate to major upgrades.

6.3 Installation Ports

There are five major ports within a distance of 200 nautical miles of the wind farm sites off Ceará's coast:

- Itaqui / São Luis in Maranhão
- Pecém in Ceará
- Fortaleza in Ceará
- Natal in Rio Grande do Norte
- Suape in Pernambuco

Each of these ports are profiled in the following sections to identify current infrastructures, potential storage areas and necessary upgrades for windfarm installation logistic operations.

The screening looks both into the short-term and long-term potential for installation ports. Port upgrades are often costly and time-consuming not only in construction time, but also time for planning and permitting. The investments often require close engagement of the ports, developers' planned project pipelines and governmental support to agree on upgrading investments. Therefore, it has been seen in emerging markets that the first wind farms installed must often make do with the current capacities of the chosen port, or only carry out moderate upgrades. These workarounds generally come at the cost of an efficient installation process. This assessment aims to show which ports could be capable of hosting a single offshore wind farm installation (based on the reference wind farm) with their current capabilities, using workarounds and accepting some inefficiencies.

If the market is successful and develops a reliable pipeline, it will be necessary to invest in port infrastructure to increase efficiency. This report refers to this as the development of a port into a regional installation hub. In this case, the port, the government, developers or other parties invest into major upgrades tailored to offshore wind with the aim to serve many offshore wind farms in a certain region, potentially even simultaneously.

6.3.1 Installation Port Benchmark Requirements

The installation port is the hub of the T&I operations. The following activities will take place in this port during the windfarm construction:

- Equipment storage: Windfarm components are manufactured in highly specialized factories that are spread all around the world. Those components must be gathered in a marshalling area prior to offshore installation to avoid inefficient voyages of expensive installation vessels.
- Component pre-assembly: WTG components are shipped in pieces and several preparation activities such as tower assembly and rigging installation need to be performed at the installation port prior to sending equipment offshore.

- Installation vessel feedering: Offshore construction works take place in two primary stages: first the foundation installation, then wind turbine generator (WTGs) installation. During installation, the installation vessel is loaded with foundations or sets of towers, nacelles and blades. It sails to the wind farm and installs the components stored on deck, then returns to port to pick up the next set of components. Such an installation vessel typically has the highest daily charter rates of all vessels used in offshore wind, therefore the need to use it most efficiently drives the project schedule. It is important that the next sets of components are already waiting at quayside when the vessel returns. Further campaigns, such as cable laying and burial also use the installation port for load out.

The Danish port of Esbjerg has been used as an installation port for several wind farms and the photo below in Figure 6-1 shows components such as towers, blades, nacelles and hubs in storage, as well as the extensive quayside for vessel load out.

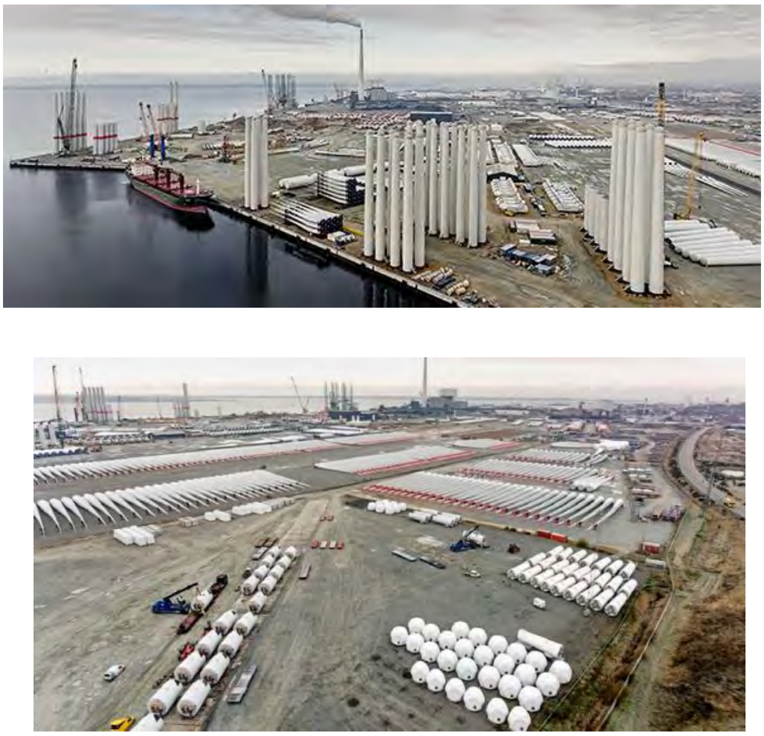


Figure 6-1: Esbjerg, major windfarm logistic hub [68]

Based on the reference wind farm in Section 3 and expected industry developments, an envelope of the components that will transit through the ports can be estimated. Table 6-2 presents the envelope considered in this study.

Table 6-2: Wind farm main components envelope

Component		Dimension		Weight
Foundation	Monopile	Length:	up to 75 m	up to 1,400 mt
		Diameter:	up to 9.5 m	
	Transition piece	Height:	up to 25 m	up to 350 mt
		Diameter:	up to 9 m	
Wind turbine	Tower (3 – 5 sections)	Length:	up to 125 m	up to 840 mt
		Diameter:	up to 8 m (per section)	
	Nacelle	Length:	up to 25 m	up to 700 mt
		Width:	up to 12 m	
		Height:	up to 12 m	
	Blades	Length:	up to 115.5 m	up to 60 mt
		Blade root diameter:	up to 5.5 m	
		Max. chord length:	up to 6.5 m	

The port benchmark criteria are driven by loading and unloading foundation or WTG components on vessels at quayside. The storage capacities will be driven by windfarm criteria such as WTG quantity and their power rating. Table 6-3 defines a benchmark for installation port requirements by grouping them in three different categories according to Ramboll's experience:

- Maritime access: the port location to windfarm area and the capacity for jack-up vessels with very high air drafts are key parameters when choosing an installation port.
- Loading and pre-assembly operations: to berth transportation vessels and pre-assemble WTG towers, the quayside shall be adapted to vessel dimensions and equipment weight.
- Storage capacity: to optimize offshore installation operations, a large number of windfarm components are stored simultaneously ahead of construction operations.

Table 6-3: Installation port benchmark

Component	Recommended	Acceptable
Maritime access		
Distance to lease area	< 100 Nautical Miles	< 200 Nautical Miles
Air draft limitation	No	100 m
Loading and pre-assembly operations		
Quay length (installation vessel)	300 m	200 m
Quay bearing capacity	40 mt/m2	10 mt/m2
Water depth at quayside	15 m	10 m
Storage capacity		
Storage capacity	> 16 ha	> 10 ha
Storage bearing capacity	10 mt/m2	5 mt/m2

It is important to differentiate between the "recommended" and "acceptable" benchmark criteria. The first are selected for ports aiming to be a windfarm installation hub used to function as a logistic harbor for consecutive projects, as well as to enable a large variety of T&I set-ups. The second lists the requirements that would enable the development of a windfarm and have a significant impact on the T&I strategy. These criteria would also limit the variety of installation and transportation vessels that can be mobilized, leading to a negative impact on the overall windfarm construction duration.

6.3.2 Port of Itaqui/São Luís

Figure 6-2: Aerial view - Port of Itaqui/São Luís

São Luís (Figure 6-2) is a port in the state of Maranhão, west of Ceará [55]. The port is located some 200 nautical miles from the most western potential wind farms of Ceará. This public harbor is an offshore port located in the Baía de São Marcos at the end of the Mearím River estuary. Most of the berths are connected to shore by bridges, however there are also berths in the southern part of the port with direct access to the onshore port area. The port is already large in size and is adjacent to further undeveloped areas, which may offer future potential for expansion. Port activities are comprised of mainly solid and dry bulk. Berths are available with a water depth of up to 18 m. Large vessels are regularly berthing in this port which benefits from transport infrastructures of the nearby city São Luís. Table 6-4 summarizes the findings:

Table 6-4: Findings – Port of Itaqui/ São Luís

	Findings
Maritime access	The port is located very far east from Ceará's coast and would be reachable for windfarms developed on the west part of the coast. The port access is not restricted in draft or air draft and is thus suitable for all types of vessels involved in wind farm construction operations.
Loading operations	Current infrastructures are missing load-out assets such as heavy-duty cranes or Ro/Ro ramps. Current quays have more than 10m water depth but are meant for light cargo operations. The limited bearing capacity would not be suitable for windfarm components without upgrade. Quaysides dimensions are suitable for transport vessels. The possibility for jack-up vessels to perform load-out operations could not be determined. Seabed reinforcement may be necessary to enable jacking up.
Storage	At the present approximately 6 hectares of potential storage area has been identified, as shown in Figure 6-2, falling far short of the 15-hectare benchmark. There is significantly more storage area existing at the port, however this is currently in use for light cargoes.

The current port infrastructures are not suitable for the installation of a 500 MW windfarm, without major quay and storage space upgrades to meet bearing capacity as well as storage area requirements. Additionally, the port would need to broaden its focus and strategy, as currently dry bulk is the focus and all other activities are very minor. Development of Port of Itaqui/São Luís to a regional windfarm construction hub would likely require expanding the port into un-developed land around the port.

6.3.3 Port of Pecém

Figure 6-3: Aerial view - Port of Pecém

Pecém has a central position on the Ceará coast making it a perfect candidate for the development of a logistic hub for windfarm construction [56]. This privately-owned harbor is an offshore port protected by a breakwater, connected to immense onshore storage areas via a bridge. In relation to offshore wind, this bridge is considered a disadvantage because it may restrict the passage of windfarm components depending on their weight and dimensions. This means that even though Pecém has an unusually large storage area behind it, the area in its current form is not effectively usable for storage of all types of wind farm components.

The port activities are quite wide-ranging: handling of solid and liquid bulks as well as transport and storage of general and oversized cargos, containers, and fuels. Large vessels regularly berth in this port. The port complex also hosts the Brazilian company, Aeris Energy. Aeris Energy currently supplies onshore wind turbine blades for Vestas, Nordex-Acciona, WEG, GE and SGRE [32]. In 2021, Aeris manufactured blades over 80 meters for Nordex-Acciona that were shipped directly from the Port complex of Pecém, CE. In the port complex, Aeris Energy has a factory with an annual production capacity of 9 GW [33]. Furthermore, CSP, a manufacturer of high-quality carbon steel slabs, are located in the Port of Pecém complex. Table 6-5 summarizes the findings:

Table 6-5: Findings – Port of Pecém

	Findings
Maritime access	The port is ideally located on Ceará coast and suitable for all types of vessels involved in windfarm construction operations. All wind farms sites in Ceará are comfortably within its reach.
Loading operations	Water depth at quayside ranges up to 15 meters and the bearing capacity reaches 10 t/m2. Current infrastructures are missing load-out assets such as heavy-duty cranes or Ro/Ro ramps. This could be solved by transporting wind farm components with heavy lift cargo vessels. Quaysides are suitable for transport vessels. The possibility for jack-up vessels to perform load-out operations could not be determined; seabed reinforcement may be necessary.
Storage	Currently only the quayside storage area of 10 hectares identified in Figure 6-3 and located on breakwater can be used. High level storage solutions shall be investigated to evaluate storage capacity on breakwater. Hauling solution to transport windfarm components between load-out location on breakwater and onshore shall be investigated to increase storage location.

The current port infrastructure is suitable to host the installation of a 500 MW windfarm without major upgrades, however the port would only host right-on-time delivery of components, with limited-to-no pre-assembly abilities and only one campaign at a time. Even such a limited set-up could potentially require moderate upgrades due to for example, load out infrastructure, seabed reinforcement and area and bearing capacity. The possibility to develop Port of Pecém into a regional windfarm construction hub depends on port capacity to connect upland storage capacities to load-out locations with a solution enabling the transfer of windfarm components onshore, or alternatively the development of a new offshore wind terminal with adequate storage.

The port of Pecém and its infrastructure are further discussed in a case study in Section 6.4

6.3.4 Port of Fortaleza

Figure 6-4: Aerial view - Port of Fortaleza

Fortaleza is located only slightly southeast of Pecém and therefore also has a central position on the Ceará coast making it a perfect location for the development of a logistic hub for offshore windfarm construction [57]. The port activities are quite wide: handling of bulk and general cargo, containers as well as liquids and fuels. Large vessels are regularly berthing in this medium size port which benefits from the transport infrastructures of the city. There are indications that Port of Fortaleza is congested, at capacity or perhaps wishes to lean towards more tourist vessel traffic, as the construction of Pecém Port aimed to reduce the load on Fortaleza [58] [59].

This public harbor is surrounded by the city with a population of ~2.5 million, including multiple universities. Stakeholder engagement pointed strongly to this advantage, as it ensures a local and educated workforce. Table 6-6 summarizes the findings:

Table 6-6: Findings – Port of Fortaleza

	Findings
Maritime access	Similar to Pecém, the port is ideally located on Ceará coast. All wind farm sites in Ceará are within 200 nautical miles.
Loading operations	Heavy-duty berths have a water depth at quayside up to 13m and a bearing capacity of 10t/m2. Current infrastructure is missing load-out assets such as heavy-duty cranes or Ro/Ro ramps. This can be solved by transporting windfarm components with heavy lift cargo vessels. Quaysides are suitable for transport vessels. The possibility for jack-up vessels to perform load-out operations could not be determined; seabed reinforcement or jack-up pads may be necessary.
Storage	A potential storage area of approximately 30 hectares identified in Figure 6-4 is partially in use. Spatial extension of the port area is not considered possible, as the area around the port is already developed. High level storage and cargo hauling solutions shall be investigated to evaluate potential improvement of harbor characteristics, such as the bearing capacities of hauling routes and storage areas.

The current port infrastructure is suitable for the development of a 500 MW windfarm without major upgrades, however may potentially require moderate upgrades due to for example, load out infrastructure, seabed reinforcement and / or limited storage area and bearing capacity. Additionally, serving such a project may require space currently utilized for other industries to be cleared, which may limit the offshore wind farm's port use, for example pre-assembly. If the Port of Fortaleza wishes to expand its involvement in offshore wind into regional hub, it will need to re-purpose storage areas inside the port and enable the installation of lifting (crane) capacities.

6.3.5 Port of Natal

Figure 6-5: Aerial view - Port of Natal

Natal is a public port located in the state of Rio Grande do Norte to the east of Ceará, located on the Potengi [60]. To access the port, ships must pass under a bridge with an air draft of 55 m at the mouth of the river. The majority of port activities are related to cruise activities, general cargo and containers necessary for fruit exportation. Medium size vessels are regularly berthing in this modest port, which is surrounded by the city of Natal. Table 6-7 summarizes the findings:

Table 6-7: Findings – Port of Natal

	Findings
Maritime access	The port is located east of Ceará, with the wind farm sites east of Fortaleza within its 200 nm radius. A strict air draft restriction due to the presence of a bridge is makes it unsuitable for jack-up vessels.
Loading operations	Current infrastructure is missing load-out assets such as heavy-duty cranes or Ro/Ro ramps. Current quays are meant for light cargo operations and would not be suitable for windfarm component without upgrades.
Storage	The potential storage area of 1 hectare identified in Figure 6-5 is currently in use and would not be sufficient for an installation port. Expansion of the port is not considered possible due to the surrounding urban area.

The current port infrastructure is not suitable for the construction of an offshore wind farm, due to air draft restriction, lack of storage space and insufficient quay infrastructure.

6.3.6 Port of Suape

Figure 6-6: Aerial view - Port of Suape

Port of Suape is the biggest port in the region of Recife, in the state of Pernambuco. Suape is quite far from Ceará's wind farms, at around 300 nm sailing distance from the easternmost wind farms in Ceará [60]. In terms of distance from the Ceará wind farms, this port would not be the first choice, but it could become necessary to use it if closer ports are unavailable. The main port activities include handling bulk and general cargo, cars, containers as well as liquids and fuels. Large vessels are regularly berthing in this medium size port which is well accessible through the infrastructure of the nearby city Recife. The public harbor benefits from nearby developed infrastructure and from a dynamic industrial area. LM Wind Power also has a factory located in the Port complex of Suape. LM Wind Power has recently expanded its production capacity for blades over 60 meters in size [34], besides securing a partnership with Vestas for the production of the V150-4.2 MW turbine blades, to begin in mid-2022 [35]. Table 6-8 summarizes the findings:

Table 6-8: Findings – Port of Suape

	Findings
Maritime access	At 300 nm from the nearest wind farms in Ceará, this port would only be used if closer ports were unavailable. It is suitable for all types of vessels involved in windfarm construction operations.
Loading operations	Current infrastructure is missing load-out assets such as heavy-duty cranes or Ro/Ro ramps. This can be solved by transporting windfarm components with heavy lift cargo vessels. With water depths up to 17m, quaysides are suitable for transport vessels given sufficient quayside bearing capacity. The possibility for jack-up vessels to perform load-out operations could not be determined; seabed reinforcement or jack-up pads may be necessary.
Storage	The storage area identified in Figure 6-6 is a generous 50 hectares in total, but currently dedicated to other use. An extension of the port or re-purposing of storage areas is likely necessary to host offshore wind activities. High level storage and cargo hauling solutions shall be investigated to evaluate potential improvement of harbor characteristics.

The current port infrastructure is suitable for the construction of a 500 MW wind farm with moderate upgrades consisting of re-purposing some storage areas currently in use. The development of Port of Suape to a regional windfarm construction hub for Ceará is very unlikely due to the distance to the wind farm sites.

6.3.7 Findings

The findings of the port profiles are summarized below in Table 6-10 with the color coding as described in Table 6-9.

Table 6-9: Result criteria for port infrastructure assessment

Result	Description
Suitable	Current port infrastructures are operational and suitable for windfarm development.
Suitable with moderate upgrades	By performing minor to moderate upgrades, the port could be suitable for the development of a windfarm. Moderate upgrades still require large investments which need to be planned and executed in advance of utilization of the port in an offshore wind project. Not performing those upgrades would result in poor port performance and constrain windfarm construction strategy.
Not suitable	Windfarm logistic requirement cannot be met without constructing new port infrastructure.

The ports are mapped in Figure 6-7.

Table 6-10: Port screening results and gap analysis

	Port of Itaqui / São Luís	Port of Natal	Port of Pecém	Port of Fortaleza	Port of Suape
Maritime access	Suitable	Air gap restriction	Suitable	Suitable	High distance to wind farm sites
Loading operations	Suitable with moderate upgrades	Suitable with moderate upgrades	Suitable	Suitable	Suitable with moderate upgrades
Storage capacity	Not suitable	Not suitable	Suitable with moderate upgrades	Suitable with moderate upgrades	Suitable with moderate upgrades
Overall suitability	Unsuitable	Unsuitable	Suitable with moderate upgrades	Suitable with moderate upgrades	Suitable with moderate upgrades
Upgrades needed for one reference wind farm	-	-	• Jack-up workability at quayside	• Jack-up workability at quayside	• Jack-up workability at quayside • Ensure storage availability
Upgrades needed to become installation hub	-	-	• Develop hauling capacity between breakwater and upland or add area to quayside • Increase load-out capacities (bearing capacity, Ro/Ro and pre-assembly cranes)	• Increase storage and load-out capacities (bearing capacity, Ro/Ro and pre-assembly cranes)	• Increase storage and load-out capacities (bearing capacity, Ro/Ro and pre-assembly cranes)

Figure 6-7: Installation ports for Ceará's wind farms

This evaluation shows that no ports have the required infrastructures to become a wind farm installation hub. By adapting the T&I strategy and finding workarounds to the current port infrastructure limitations, two ports located in state of Ceará are suitable with potential moderate upgrades to perform as installation ports for right-on-time supply of one wind farm: Pecém and Fortaleza. Both of these ports cover most of Ceará's wind farm sites within the recommended 100 nautical mile radius and all wind farm sites within the acceptable 200 nm radius. The port of Suape is too far south of Ceará's wind farms to be considered as an installation port in normal circumstances, but in the event that Pecém and Fortaleza are not available, it may be used.

If Ceará's pipeline develops well and the volume of offshore wind farms under construction increases, additional major investments will be required for both Pecém and Fortaleza. Pecém would need to either better connect its quayside to its onshore storage areas or to build additional storage areas offshore. Fortaleza would only need to increase storage capacity dedicated to offshore wind but is likely limited to a total of 30 hectares.

Pecém and Fortaleza are also within range of offshore wind farms planned in the states of Piaui and Rio Grande do Norte and would likely be used to serve them, as there are no other suitable ports closer to those wind farms. The easternmost wind farms planned in Rio Grande do Norte, are equally close to the Port of Suape and the Port of Fortaleza and could well be served by Suape. While it is unlikely that all the currently planned wind farms will be realized, the concentration of planned wind farms at the doorstep of Pecém and Fortaleza is likely to encourage attention to offshore wind and development in this direction.

6.4 Case Study – Port of Pecém

Though the nature of this report is a high-level overview, it was desired by the INNOWIND project partners to include a case study which goes into additional detail. The Port of Pecém was a natural candidate for such a case study, as it has been actively interested in offshore wind in Brazil for some time and in dialogue with the INNOWIND project partners. This case study looks into two scenarios for the Port of Pecém:

- A utilization plan for the port using its current infrastructure to host the T&I activities for a single 500MW wind farm, and
- An upgrade and utilization plan for transforming the port into an ideal regional offshore wind hub for T&I, which is also capable of serving as the installation port for multiple wind farms at once.

6.4.1 Development of a 500 MW Windfarm with Current Infrastructure

The aim of this section is to evaluate potential port logistic solutions that would fit with current infrastructure and/or require minor to moderate upgrades. These are the type of "workarounds" that are typically seen for the first offshore wind farms in a region, where the business case for further investment is not yet certain enough to support costly upgrades. In this scenario, the Port of Pecém has a few challenges that must be addressed:

- Separation of quayside and main storage area by a bridge that is considered not passable with benchmarked windfarm components
- Insufficient storage area at quayside
- Insufficient quayside bearing capacity for WTG tower assembly

These limitations, in particular the storage area, mean that the port will not be able to store both WTG components and foundations at the same time, nor all components for either full campaign at once: right-on-time delivery will be necessary in batches. This analysis considers that the logistics will essentially be broken into two steps: first the foundation installation campaign is completed and then the turbine installation is completed afterward. This is less efficient than a typical wind farm installation campaign, which may overlap foundation and WTG installation campaigns or have a higher percentage of components ready for load out than right-on-time delivery would allow.

Below, Figure 6-8 shows the logistics flow and potential utilization of the port using current infrastructure. The numbers in the figure correspond to the steps described in the paragraphs below it.

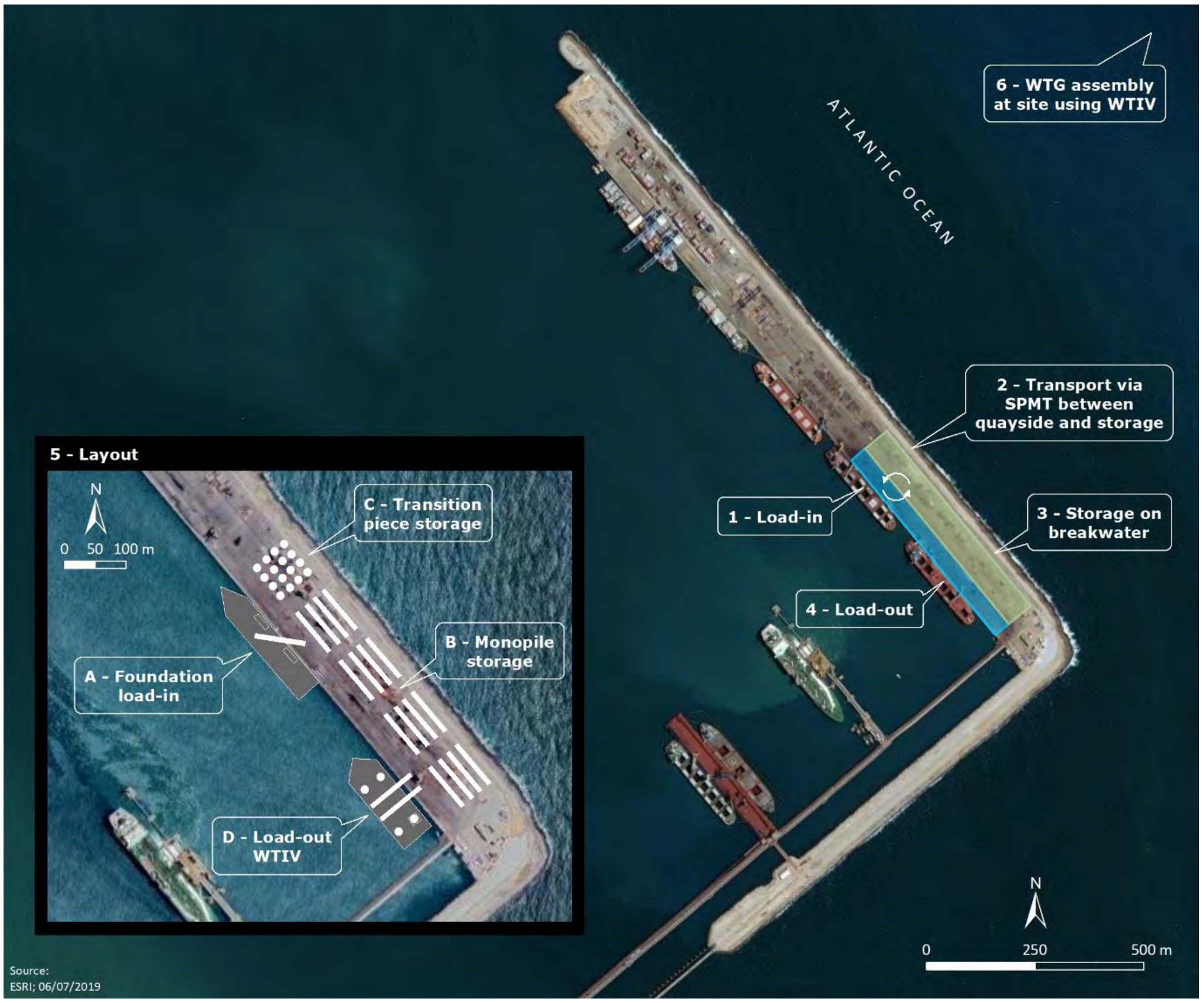


Figure 6-8: Potential usage for port of Pecém with current infrastructure

Load-in:
The load-in of foundations and WTG components can be done either by shore cranes, by transportation vessels or rolled out using dedicated machines (1). According to current port infrastructure, the best solution would be to ship very heavy components on transportation vessels with heavy lift cranes similar to the one presented in Figure 6-9. This would allow for the components to be transferred to Port of Pecém without the required addition of large lifting infrastructure on land.

Alternatively, a mobile crane with adequate lifting capacity could be deployed or a dedicated mooring arrangement for rolling operations could be set up. Both solutions would require more substantial port upgrades.

Figure 6-9: Transportation vessel with heavy lift cranes [61]

Storage:

After load-in, the foundations or WTG components will need to be moved to a storage area. The storage area shown in Figure 6-8 reflects the area that the port has indicated can be made available. Current port infrastructure does not make it possible to haul very heavy components to the onshore storage location. Therefore, a storage solution on the breakwater is needed (3). Such a solution may require rearranging the overall port logistic set-up to find an appropriate storage solution to adapt to bearing capacity. Figure 6-10 shows a potential solution based on gravel berms to spread monopile weight. Some minor upgrades will be required to support wind turbine components as well. The mobilization of self-propelled modular trailer with sufficient capacity will be needed to haul the various components (2).

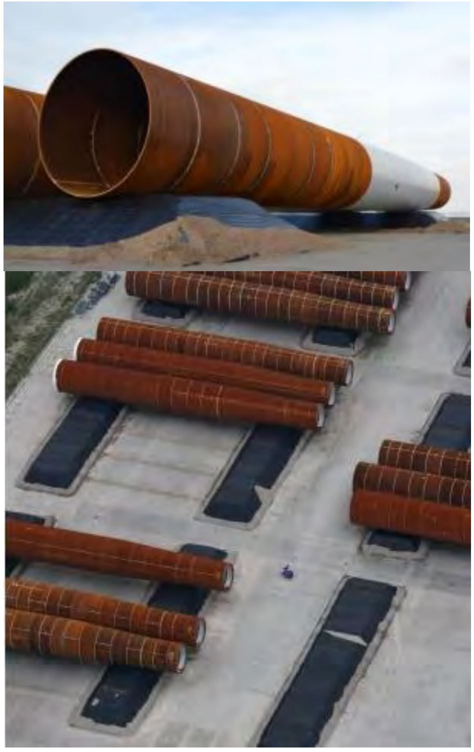


Figure 6-10: Foundation hauling and storage [62]

Load out:

Due to shallow wind farm water depth (Section 3), it is likely that jack-up vessels will be selected for the installation of all wind farm components. To perform any lifting operation, jack-up vessels lift themselves above water through stabilizing four to six 'legs' on the seabed. This procedure is known as 'jacking-up'. This allows the vessel to use their cranes at full capacity, as can be seen in Figure 6-11 (4).

Figure 6-11: Foundation load-out using a jack-up vessel [63]

To perform jacking-up operations, specific soil conditions are required. This holds true both offshore during installation, as well as when performing load-out in a port. A site assessment is required to ensure feasibility and evaluate potential soil upgrade for safe jacking procedures. Many offshore wind ports are required to create jack-up pads, where these vessels can perform their lifting operations.

The inset map in Figure 6-8 shows a potential for load-in and load-out, which keeps adequate space available for other port operations (5). This layout would enable the storage of up to 16 foundation units, which is about 50% of units. The remaining 50% would need to be delivered right in time. This number of units would give enough buffer in the installation campaign schedule and reduce risks associated with just in time delivery strategy.

About eight sets of turbine components could be stored on the breakwater at once but would need approximately 50% more room than shown for the foundations. Around four deliveries of component sets will be required for a 500MW wind farm. The additional space needed for this would limit other port operations and either Ro/Ro capacity or cranage would be needed to move the components.

Alternatively, the turbine staging and installation could be performed from another port entirely, such as Fortaleza.

WTG assembly:

The tower pre-assembly and pre-commissioning operations are usually performed in the installation port to reduce the duration of offshore installation operations. A dedicated crane with large lifting height and capacity is mobilized on the quayside to perform those operations. Several challenges are associated with these operations:

- high quayside bearing capacities to sustain assembled WTG tower (up to 1050 mt) and mobile crane
- blocked quayside during the offshore installation campaign

As a temporary solution to avoid major port upgrades and the mobilization of costly equipment, the pre-assembly could partially or entirely be performed on the installation vessel or offshore by the installation vessel as seen in Figure 6-12 (6). This solution increases the duration of the offshore operations at the cost of the wind farm.

Figure 6-12: WTG assembly offshore [64]

6.4.2 Upgrades to Develop to a Windfarm Installation Hub

The logistic concept described above can be utilized as a workaround for the first wind farms to be installed out of Pecém, but if the project pipeline is large enough, it will soon be economically viable to upgrade the port so that it can function as a wind farm hub. This hub has ideal facilities for offshore wind and the ability to serve projects simultaneously. This upgrade must achieve several goals:

- Increase the available storage area
- Enable WTG pre-assembly at quayside
- Enable use of Ro/Ro loading

To achieve these goals, Ramboll has identified two alternatives:

- Alternative 1: upgrade of current infrastructure: reinforcing the bridge to reach onshore storage locations combined with several quayside upgrades could enable the port to become a regional logistic hub. This would have a negative impact on current port activities due to the footprint of wind farm components and the associated hauling constraints.
- Alternative 2: construction of a terminal dedicated to offshore wind: the development of new infrastructure is a solution to build an optimized storage area, heavy duty quaysides and load-out facilities.

The construction of a new quay would enable Pecém to create an ideal port for offshore wind and is likely the solution favored by most T&I stakeholders. However, it is also likely to be the most expensive solution, as 16+ hectares of land must be reclaimed from the sea. It should be noted that large upgrade projects also add local jobs during construction, adding an economic benefit for expensive conversions. Simply upgrading the current infrastructure has the disadvantage that some inefficiency is caused by double-handling of the components to between the quayside and storage area. The main advantage of this alternative is that it is likely to be less expensive than a new quay and could be constructed in phases. As the available storage area in the Pecém complex is in the thousands of hectares, this alternative could also provide access to more storage space in total, as well as to potential future manufacturing in the port complex.

The decision on which of these alternatives to choose is a complex one that is also heavily influenced by the business case and certainty of the offshore wind pipeline. It is therefore recommended that a comparative feasibility study of both options is conducted.

6.4.3 Alternative 1 – Upgrade of Current Infrastructure

Below, Figure 6-13 shows the necessary upgrades for the port of Pecém to make its current infrastructure suitable for large volumes of offshore wind. The numbers in the figure correspond to the steps described in the paragraphs below it.

Figure 6-13: Potential usage of port of Pecém with upgraded infrastructure

Storage area:

The most important role of an installation port in the construction of an offshore windfarm is the marshalling activities that ensure enough buffer storage to feed offshore operations. In Table 6-3 a minimum storage area of 16 hectares is considered as a reasonable size to simultaneously store all WTG components. Therefore, Port of Pecém needs to expand its storage capacity.

In this alternative, equipment is hauled towards onshore storage area. Currently it is not thought that the existing bridge, shown in Figure 6-14 and Figure 6-15, will have the strength to allow heavy components to pass, however as an expansion of the bridge would be costly, it is recommended to conduct an in-depth engineering review of the bridge's capacity.

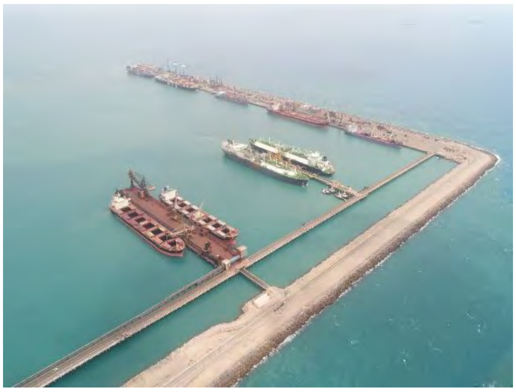


Figure 6-14: Pecém bridge and breakwater, photo courtesy of port of Pecém

The study shall also and identify required upgrade works, to achieve the necessary strength. It is recommended that the use of the road on the breakwater is considered as well (1).

The constraints related to hauling of heavy and bulky components such as foundation, blades and nacelles using SPMTs shall be considered in the assessment. This may discover the need for significant upgrades of current infrastructures or in the construction of an exclusive bridge for these types of operations.

Load-out infrastructure:
To be able to improve port's competitiveness, the capacity to have infrastructure capable of loading/unloading of a large variety of vessels is the key. A very efficient and cost-effective way of doing it is by rolling very large cargos on vessel decks using SPMTs as can be seen in Figure 6-16. This load-out solution is widely used in the offshore wind industry and is considered as essential to be able to operate a wide range of transportation as well as installation vessels.

The current configuration of the internal bridges and berths does not have enough space for maneuvers. Therefore, it is highly recommended to consider the construction of a Ro/Ro quay and the associated berthing facility when developing the port to an offshore wind farm installation hub (2).

As jack-up vessels are currently considered the backbone of all wind farm installation campaigns, having the capacity for WTG installation vessels to load multiple WTG sets in port and shuttle to installation location is the key. Therefore, a windfarm development logistic hub shall be suited for jack-up operations. Depending on soil conditions and port infrastructure a dedicated seabed reinforcement may be required on several berths to accommodate jacking operations. Therefore, the assessment of seabed upgrade requirement and their potential implementation shall be considered within the port strategy.

Figure 6-15: Pecém view of storage area to quay

Figure 6-16: Roll-in / Roll-out Foundation transfer

Quayside upgrades:
WTG pre-assembly activities as shown in Figure 6-17 requires the mobilization of large cranes. To be able to withstand the lifting operations and the WTG components' weights a very high quayside bearing capacity is required. A feasibility study should be performed to identify a quayside area that could be dedicated to WTG tower pre-assembly and would assess the upgrade works required to reach up to 40 t/m2 bearing capacity (3).

Figure 6-17: WTG pre-assembly at quayside [65]

6.4.4 Alternative 2 – New Construction of an Offshore Wind Terminal

Of all the logistic concepts presented in this report, the new construction of an offshore wind terminal is the least complex. Below, Figure 6-18 shows that a single area of at least 16 hectares would be added to the end of the existing quay, to benefit from the deeper water depth of that area. (1). This alternative has several advantages:

- Offshore wind activity stays contained within a certain area of the port and does not block other operations
- The new terminal can also be planned as a multi-purpose terminal, which can be used for other operations during the time between offshore wind farms
- The handling of wind farm components is as time and cost-effective as possible

Figure 6-18: Potential usage of Port of Pecém with new offshore wind terminal

These two alternatives have shown that port expansion to an offshore wind farm logistic hub is feasible. In this section, various solutions and key port requirements have been highlighted. It is also important to keep in mind that upgrade of port infrastructure is a very long process. It must be planned carefully taking permitting, environmental, economic, engineering, and operational constraints into account before being able to start upgrade works. Therefore, the development of new infrastructure shall be evaluated and started soon for the Port of Pecém to be operational for the construction of the first offshore wind farms and become a major player in Brazil.

6.5 Operation and Maintenance Ports

Ports used for operation and maintenance (O&M) have much lower technical requirements than installation ports. Compared to construction operations, mobilization duration is shorter, vessel and component quantities are less, and sizes are much smaller.

There are two types of O&M base ports:

- Daily operations: port where crew transfer vessels (CTV) are departing to wind farm location on regular basis to bring workers to site for regular maintenance purposes. An example of a daily operations port using CTV, the British port of Barrow Harbor, can be seen below in Figure 6-19. Though this report only considers CTV-based concepts, there are also maintenance concepts which use service operation vessels (SOVs). These vessels, such as Ørsted's "Wind of Change" (84m long, 20 wide and 5m draft) are larger vessels including cranes, helideck, onboard warehouses and workshops, daughter vessel and crew lodging. They stay at sea for up to two weeks at a time, rather than coming back to port daily. These vessels are purpose-built for wind farms and are economically feasible when large number of wind farms in the same area are maintained by the same owner, so they have only been seen in mature markets thus far. A service concept based on SOV would put slightly higher requirements on port infrastructure but lower requirements on distance to port.
- Major repairs: port is used as a logistic base for large maintenance campaigns such as major component replacement and detailed inspections. Medium-sized assets such as jack-up vessel or accommodation vessel are mobilized during those works. If large and/or heavy components such as blades or nacelles need to be replaced, the requirements on the quay parameters are similar to those for the installation port.

Figure 6-19: Barrow harbor with crew transfer vessel pontoon [66]

6.5.1 Operations and Maintenance Port Requirements

To derive benchmark requirements for these two types of ports, Table 6-11 groups the criteria in three different categories according to Ramboll's experience:

- Daily operations: the sailing time to wind farm location must be reduced to less than 2 hours since workers are regularly commuting to the farm location. CTVs have similar dimensions to fishing boats.

- Major Repairs: major repair logistic port can be located further away from the windfarm. Requirements are dictated by the necessity to berth larger vessels, such as jack-up vessels or SOVs, and handle nacelle and blades logistics.

Table 6-11: Operation and maintenance port benchmarks

Component	Major Repairs	Daily Operations
Distance to wind farm	< 200 Nautical Miles	< 30 Nautical Miles
Air draft limitation	100 m	10 m
Quay length	150 m	40 m
Water depth at quayside	10 m	3 m
Storage capacity	> 3 ha	> 2 containers

6.5.2 Findings

There are eleven ports which were evaluated as potential daily operations port, major repair port or both for the Ceará wind farms:

- Itaqui / São Luis in Maranhão
- Luis Correia in Piaui
- Camocim in Ceará
- Paracuru in Ceará
- Pecém in Ceará
- Fortaleza in Ceará
- Fortim in Ceará
- Grossos in Rio Grande do Norte
- Cabedelo in Paraiba
- Natal in Rio Grande do Norte
- Suape in Pernambuco

Due to the number of wind farm sites currently being considered and the stringent requirements in terms of distance to wind farm, it is expected that multiple ports will be used as O&M bases. Based on benchmark criteria, most fishing ports fulfill the minimum requirements for daily O&M operations, while ports with more significant infrastructure are needed for major repair campaigns. Table 6-12 summarizes the ports and their suitability.

If we examine the spatial distribution of the ports suitable for daily operations, as shown below in Figure 6-20, it can be seen that the Ceará's coast is well covered, except for wind farms planned between the Port of Camocim and the Port of Paracuru. In the short term, this gap could be closed by using an SOV instead of CTV to perform the daily maintenance of those windfarms. This would need to be evaluated on a case-by-case basis for each wind farm. In the long term, a new O&M port would need to be constructed.

Table 6-12: O&M port suitability [67]

Location	Current Use	Suitable for Daily Operations?	Suitable for Major Repairs?	Comments
Sao Luis	Light cargo harbor		✓	Long distance to windfarm
Luis Correia	Fishing and some leisure	✓		Not suitable for vessels other than CTV
Camocim	Fishing and some leisure	✓		Not suitable for vessels other than CTV
Pecém	Multi-cargo harbor	✓	✓	Centrally located
Paracuru	O&G harbor	✓	✓	Centrally located, SOVs only
Fortaleza	Multi-cargo harbor	✓	✓	Centrally located
Fortim	Fishing and some leisure	✓		Not suitable for vessels other than CTV
Grossos	Fishing and some leisure	✓		Not suitable for vessels other than CTV
Port of Natal	Multi-cargo harbor		✓	Long distance to windfarm, SOVs only
Port of Cabedelo	Oil and gas and multi-cargo harbor		✓	Long distance to windfarm
Port of Suape	Multi-cargo harbor		✓	Long distance to windfarm

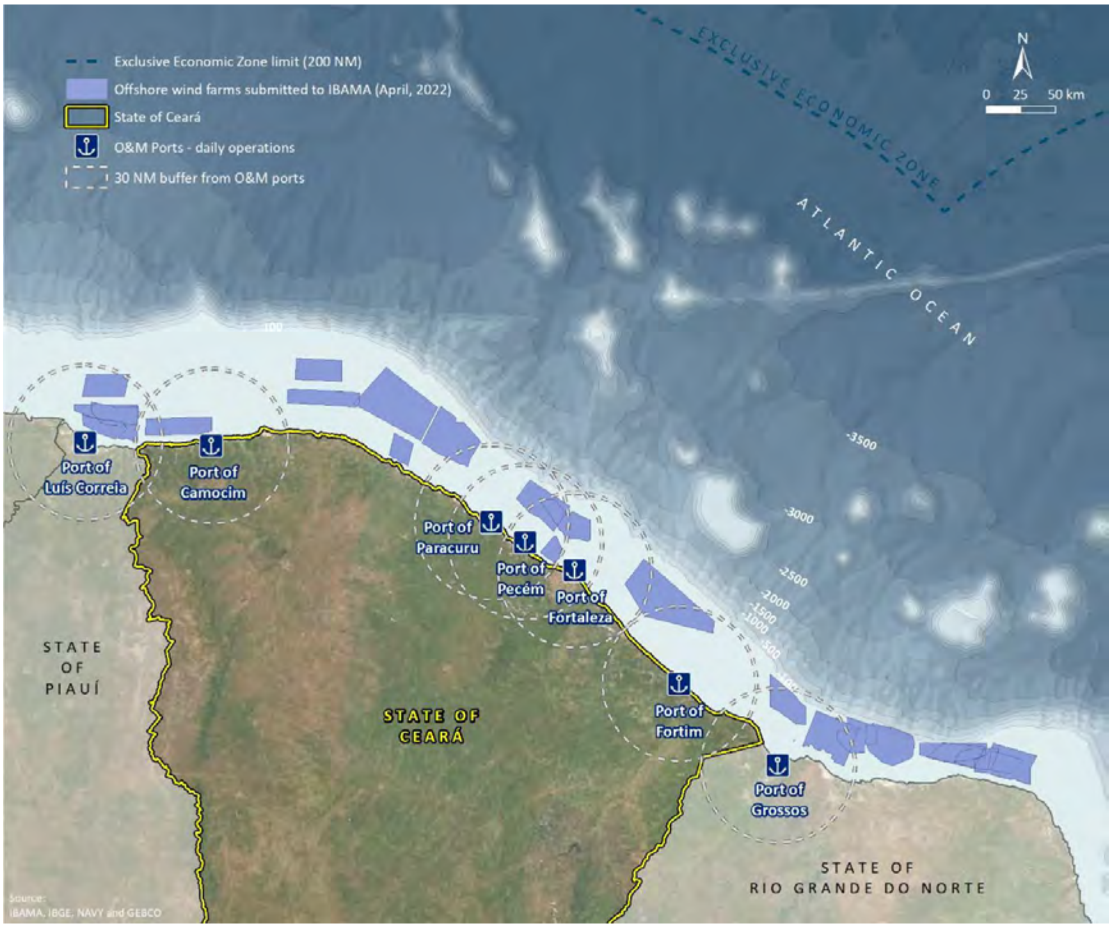


Figure 6-20: Ports suitable for O&M daily operations

The ports suitable for major repairs have larger ranges, as shown in Figure 6-21 below.

Figure 6-21: Ports suitable for O&M major repair campaigns

These larger radii result in a seamless coverage of Ceará's wind farms. Similar to the situation with installation ports, Pecém and Fortaleza can cover the entire coast of Ceará and this time they are also joined by the Port of Paracuru. These ports can also cover the wind farms planned in Piaui and Rio Grande do Norte, but the port of Itaqui would also be an option for the Piaui wind farms and Natal would be an option for the Rio Grande do Norte wind farms. However, major repair campaigns are infrequent and if the Ceará ports gain a first mover advantage as installation ports, they may become the most economical choice also for major repair campaigns.

7

Key Factors for Development of Offshore Wind in Ceará

This study explored Brazil's potential as an offshore wind market through evaluating the supply chain and port infrastructure available for offshore wind farms in the waters of Ceará. It was found that Brazil's skilled onshore wind and oil and gas workforce already holds many key competencies the offshore wind industry will require, though the speed with which the local supply chain can adapt to serve offshore wind will depend significantly on the volume of committed offshore wind projects. Established markets, such as Denmark, can assist in covering supply chain gaps in the short-to-mid-term, as well as be valuable business partners over the long-term. Overall, the outlook for Ceará and Brazil is positive, as clearly demonstrated by the extensive market interest in offshore sites.

However, as with any emerging market, there are further important development factors which both the state of Ceará and Brazil as a whole should consider. Fundamentally, these development factors are the same for all emerging markets. Recognizing this, the World Bank released a key study in 2021 titled *Key Factors for Successful Development of Offshore Wind in Emerging Markets* [5]. In this study, each development factor is analyzed with lessons learned from various offshore wind markets globally. The relative importance of each factor is different for each country, depending on its current situation. Based on the analysis performed for this report as well as stakeholder engagement, Ramboll considers the factors discussed below to be the most important for Ceará and Brazil to keep the current momentum seen in offshore wind's development in Brazil.

Clear Vision and Policy Targets

Clear and time-bound (e.g., 5-year, 10-year, 20-year, etc.) targets set by state or national governments for the inclusion of defined volumes (GW) of offshore wind into the energy portfolio sends a committed message to both the local supply chain and the international offshore wind industry of intention to develop. Many countries (or regions) have published offshore wind visions and / or sets of targets, which increases investor confidence, as well as the willingness to develop local supply chains. When these long-term plans come with a defined framework and strategy to meet the targets, suppliers are given confidence to begin establishing their own pipelines.

A clear vision, including policy targets and commitments, from the Brazilian government or the Ceará government would signal the emerging offshore wind industry that investments and resource allocation are in line with the drive of the government. This vision would also need to communicate the rationale for offshore wind in Brazil, given that less costly and already established renewable options, such as onshore wind, exist and have further potential for expansion [16]. Stakeholder discussions during the writing of this report indicated positive market perception of the state of Ceará's engagement in establishing offshore wind, including supporting the demonstrator project and the active interest of the Port of Pecém [4]. However, stakeholder discussions also signaled prohibitively high uncertainty in Brazilian offshore wind to begin supply chain or other investments. Defining clear and time-bound targets, visions and commitments will assist in reducing uncertainty, allowing for timely development of local supply chains.

Straightforward Sectoral Planning and Leasing Terms

The IBAMA publication from 13. April 2022 shows 50 potential offshore wind sites, many of which are overlapping [6]. This map does not include further competing interests in the waters of Brazil, including but not limited to oil and gas exploration and fishing. The oil and gas market is a well-established industry, particularly along the south and southeast coasts of the country. With an economy closely tied to fossil fuel production, development of a new industry which may utilize the same physical areas may be concerning to established players. To ensure harmony between offshore wind with other industries, thorough stakeholder engagement is necessary, ideally through the definition or update of a marine spatial plan at the regional or national level.

It must also be clearly defined for developers how they will be able to secure seabed leases. The interest shown from potential developers in offshore wind in Brazil has been strong but is rapidly reaching a tipping point in market perception. Stakeholder engagement has likened the current situation to a gold rush: overlapping wind farm sites with a very low bar for entry, leading to lack of meaningful commitment behind the planning. As the global market is projected to grow dramatically in the coming years, established offshore wind supply chain participants are expected to use their position in a seller's market to pick the most attractive markets and projects. Brazil must be seen as a serious market in order to attract these participants, which means acting quickly to curb perceived speculation and demonstrate that there is a route to market for serious project developers. The seabed lease award process, through for example competitive auctions, is recommended to include pre-qualification of bidders via capability assessments, as well as timebound milestone commitments to ensure that the wind farms are installed.

Pave the Route to Market

Along with sectoral planning and defining lease terms, Brazil must soon outline the government's route to market for developers. The government's policies and frameworks will be key in developing market confidence in long-term, offshore wind investments. A few examples of how this can be done include:

- Establishing guidelines for an auction process
- Providing favorable policies on offtaker agreements, considering offshore wind projects are often over 500 MW and are likely not to have one consumer, as for example, a corporate power purchase agreement may
- Designing frameworks to drive price competition
- Ensuring competitively priced, stable and reliable finance availabilities
- Encouraging supply chain competition and international collaboration, as well as
- Developing revenue support frameworks to reduce international investor risk of inflation or currency fluctuations [5].

As Brazil defines the available route, or routes, to market, it is recommended to consider the additional challenges the first offshore wind farms will face and acknowledge that the costs of the first gigawatts will be higher than of those following. Through paving the route to market for developers, the Brazilian offshore wind industry can begin to concretely plan for projects.

Balancing Public and Private Investment

Within the past five years, the COVID-19 pandemic and subsequent recovery, as well as the political environment, has left the Brazilian Real in a weak position: high currency fluctuation and interest rate spikes results have increased the cost of capital in Brazil. For the emerging offshore wind market, this will require clear paths to mitigate the financial risks for investors.

Emerging markets frequently split the revenue from an offtake agreement between local currency and a hard currency [5]. As offshore wind projects are often large and always long-term, this method allows both procurers and international investors to minimize potential currency exposure through the offtake agreement contractual structure [5]. Brazil may wish to consider this and further such options to assist in mitigating the risk and attracting international investment to their high-potential offshore wind market.

Further steps which Brazil or Ceará can consider are to balance the private investments with public funding. Investing in an emerging market comes with many risks for a local supply chain, especially for first movers, such as ports. To help balance these, governments can support through tax incentives, export credit agencies, and / or competitions for capital support or research and development support [5]. Public funding opportunities would help to balance the investment risk in offshore wind, as well as signal a proactive and supportive regulatory environment.

Ensuring Steady Development

A supplier for an offshore wind farm is required to fabricate a large set of components relatively quickly. Should that supplier not have a nearly continuous set of orders for offshore wind farms, the scaling of workforce is unlikely to be feasible. To establish a healthy, local supply chain, companies must be able to rely on a clear and continuous pipeline of orders.

The booming potential of Brazil's emerging market must be balanced with ensuring suppliers, who invest to serve the new market, can profit long-term. State and national governments can design their frameworks and strategy to ensure steady development of the offshore wind industry. This will help local suppliers scale up at a manageable speed, and continue to deliver for both the Brazilian, and potentially, global offshore wind industry.

Connecting to the Grid

While not covered in within the scope of this report, a key success factor to be considered by every offshore wind emerging market is early planning and infrastructure upgrades for feed-in of power to the transmission grid. Countries handle the interface to and ownership of grid connection assets differently. Brazil should consider the various benefits of the possible scenarios, then clearly define the roles and responsibilities. This will help to initiate early engagement with developers and transmission system operators to jumpstart one of offshore wind's most complex interfaces.

Establishing Industrial Clusters

Emerging markets, even those with beneficial related industries such as Brazil, often struggle with the logistic requirements of offshore wind. With massive components in both dimensions and mass, transport to the installation port can prove a large challenge and existing inland facilities for major components cannot typically be utilized. The infrastructure challenges which Brazil faces are common in offshore wind emerging markets. While most of offshore wind fabrication and installation takes place on the coast, the fabricators also rely on smaller components and materials which are delivered via land. For land delivery, Brazil's supply chain may encounter logistic obstacles due to limited, outdated or fragile interstate and highway systems. A potential way to relieve this burden is to establish industrial clusters for offshore wind around a port. In Ceará, the Port of Pecém is a clear potential choice for such a cluster, given its central location and generous available onshore area, which already hosts onshore blade manufacturer Aeris Energy.

State and national governments can assist in facilitating such industrial clusters through policy creation, as well as funding of business networks and further initiatives to support collaboration and investment [5]. An offshore wind installation hub can truly set itself apart in the industry through providing a complex for offshore wind related businesses to establish their facilities close to the offshore departure point. Such clusters can also provide auxiliary services relevant for the offshore wind industry. A few examples may be safety training centers specialized in the certified offshore trainings, such as Global Wind Organization-certified trainings. All personnel traveling offshore to the wind farm, during construction as well as operation, will require these trainings, as well as regular refreshers every few years. The port may also house buildings on site or nearby for operations and maintenance activities, such as marine coordination centers or spare part warehouses. Often O&M ports are positioned on shore in the closest vicinity to the offshore wind farm as possible, however this often means smaller ports are utilized. An offshore wind installation hub has the opportunity to still act as the main port for larger maintenance campaigns and / or house the larger required spare parts. A final example of auxiliary service which an offshore installation hub may consider would be the offshore helicopter transfer industry. Infrastructure required would include helipads, access to aviation fuel and hanger space with coordination and accommodation rooms. The Port of Pecém has the space and potential to develop into such an industrial cluster should the proper incentives and support be received.

8

References

[1] Energy Research Office, EPE, *Brazilian Offshore Wind Roadmap - Interactive English Version,* 2020.

[2] The World Bank, "Offshore Wind Technial Potential in Brazil," 05 2020. [Online]. Available: https://documents1.worldbank.org/curated/en/902341586847107376/pdf/Technical-Potential-for-Offshore-Wind-in-Brazil-Map.pdf.

[3] Sistema FIEC, et. al, *Ceara Wind and Solar Atlas,* 2019.

[4] Renewables Now, "Brazil's State of Ceara Reports Progress with 15-MW Offshore Wind Project," 2021. [Online]. Available: https://renewablesnow.com/news/brazils-state-of-ceara-reports-progress-with-15-mw-offshore-wind-project-748653/. [Accessed 20 07 2022].

[5] World Bank Group, *Key Factors for Successful Development of Offshore Wind in Emerging Markets,* 2021.

[6] IBAMA: Instuto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis Diretoria de Licenciamento, *COMPLEXOS EÓLICOS OFFSHORE - Projetos com processos de licenciamento ambiental abertos no IBAMA,* 2022.

[7] ABEEólica – Brazilian Wind Energy Association, *InfoVento 23 - 23. November 2021,* https://abeeolica.org.br/wp-content/uploads/2021/11/2021_11_InfoVento23.pdf, 2021.

[8] Energy Research Office, EPE, *Brazilian Energy Balance (BEN) Summary Report 2021 - Reference Year 2020,* 2021.

[9] Global Wind Energy Council, GWEC, *Global Wind Report 2021,* 2021.

[10] Renewables Consulting Group, RCG, *Global Offshore Wind: Q3 2021 Market Update,* 2021.

[11] Díario Oficial da União, "DECRETO Nº 10.946, DE 25 DE JANEIRO DE 2022," 2022. [Online]. Available: https://www.in.gov.br/en/web/dou/-/decreto-n-10.946-de-25-de-janeiro-de-2022-376016988. [Accessed 17 05 2022].

[12] EPE-Ministério de Minas e Energia, "Roadmap - Eólica Offshore Brasil. Perpectivas e Caminhos Para a Energia Eólica Marítima," 2020. [Online]. Available: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/roadmap-eolica-offshore-brasil. [Accessed 25 04 2022].

[13] United Nations, "Development of a National Marine Spatial Planning Process," by Brazilian Government (Government), 2017. [Online]. Available: https://oceanconference.un.org/commitments/?id=19704. [Accessed 25 04 2022].

[14] ANEEL, "Agencia Nacional de Energia Elétrica," 2022. [Online]. Available: https://app.powerbi.com/view?r=eyJrIjoiNjc4OGYyYjQtYWM2ZC00YjllLWJlYmEtYzdkNTQ1MTc1NjM2IiwidCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9. [Accessed 17 05 2022].

[15] Offshore Wind Biz, "Ocean Winds Launches OW Brasil, Plans 15 GW of Offshore Wind," 14 06 2022. [Online]. Available: https://www.offshorewind.biz/2022/06/14/ocean-winds-launches-ow-brasil-plans-15-gw-of-offshore-wind/. [Accessed 20 07 2022].

[16] Energy Research Office, EPE, *Wind Farms at the End of Expected Lifetime,* 2022.

[17] Energy Research Office et. al, EPE, *PDE 2029 - Ten-Year Energy Epansion Plan Executive Summary - English,* 2021.

[18] Ceará Governo do Estado, "Government of Ceará and Qair Brasil Sign an Agreement for the Development of Renewable Energy Projects with an Investment of US$ 6.95 Billion and

Generation of 2,600 Jobs," 2021. [Online]. Available: https://www.ceara.gov.br/2021/07/06/governo-do-ceara-e-qair-brasil-assinam-acordo-para-desenvolvimento-de-projetos-de-energias-renovaveis-com-investimento-de-us-695-bilhoes-e-geracao-de-2-600-empregos/. [Accessed 20 07 2022].

[19] 4C Offshore, *Global Market Overview - Q1 2022 Slide Deck,* 2022.

[20] Offshore Wind Biz, "Petrobras Reveals 4 GW Offshore Wind Power Play in Brazil," 19 05 2022. [Online]. Available: https://www.offshorewind.biz/2022/05/19/petrobras-reveals-4-gw-offshore-wind-power-play-in-brazil/. [Accessed 20 07 2022].

[21] International Renewable Energy Agency, IRENA, *Renewable Energy Benefits: Leveraging Local Capacity for Offshore Wind,* 2018.

[22] Vestas , "https://www.vestas.com/en/products/offshore/offshore-solutions," 2021. [Online]. Available: https://www.vestas.com/en/products/offshore/offshore-solutions. [Accessed 18 04 2022].

[23] Siemens Gamesa Renewable Energy S.A., "https://www.siemensgamesa.com/en-int/products-and-services/offshore," 2022. [Online]. Available: https://www.siemensgamesa.com/en-int/products-and-services/offshore. [Accessed 18 04 2022].

[24] General Electric, "https://www.ge.com/renewableenergy/wind-energy/offshore-wind," 2022. [Online]. Available: https://www.ge.com/renewableenergy/wind-energy/offshore-wind. [Accessed 18 04 2022].

[25] ABDI - AGÊNCIA BRASILEIRA DE DESENVOLVIMENTO INDUSTRIAL, "Atualização do Mapeamento da Cadeira Produtiva da Indústria Eólica no Brasil," 2017. [Online]. Available: http://inteligencia.abdi.com.br/wp-content/uploads/2017/08/2018-08-07_ABDI_relatorio_6-1_atualizacao-do-mapeamento-da-cadeia-produtiva-da-industria-eolica-no-brasil-WEB.pdf. [Accessed 16 04 2022].

[26] Ceará Government, "https://www.ceara.gov.br/2019/11/12/inaugurada-nova-fabrica-de-turbinas-de-energia-eolica-em-aquiraz/," 12 11 2019. [Online]. Available: https://www.ceara.gov.br/2019/11/12/inaugurada-nova-fabrica-de-turbinas-de-energia-eolica-em-aquiraz/.

[27] Panorama Offshore, "Siemens Investe em Produção de Conversores no Brasil," 25 08 2019. [Online]. Available: https://www.cimm.com.br/portal/noticia/exibir_noticia/18630-siemens-investe-em-producao-de-conversores-no-brasil. [Accessed 20 07 2022].

[28] GE Press Release, "https://www.ge.com/news/press-releases/ge-renewable-energy-anuncia-primeiro-contrato-para-venda-da-turbina-eolica-cypress," 8 10 2019. [Online]. Available: https://www.ge.com/news/press-releases/ge-renewable-energy-anuncia-primeiro-contrato-para-venda-da-turbina-eolica-cypress.

[29] Petronoticias, 04 02 2021. [Online]. Available: https://petronoticias.com.br/nordex-monta-fabrica-para-atender-projeto-eolico-na-bahia-e-preve-pico-de-ate-350-empregados-na-unidade/.

[30] WEG, "https://www.weg.net/institutional/BR/pt/news/produtos-e-solucoes/weg-e-engie-brasil-energia-concluem-instalacao-do-primeiro-aerogerador-nacional," 11 06 2021. [Online]. Available: https://www.weg.net/institutional/BR/pt/news/produtos-e-solucoes/weg-e-engie-brasil-energia-concluem-instalacao-do-primeiro-aerogerador-nacional.

[31] Portal Energia, "https://www.portal-energia.com/emprego-e-recrutamento-wobben-windpower-enercon-brasil/," 24 02 2019. [Online]. Available: https://www.portal-energia.com/emprego-e-recrutamento-wobben-windpower-enercon-brasil/.

[32] Aeris Energy, "https://api.mziq.com/mzfilemanager/v2/d/4270cd01-7524-4011-ae86-d125baa81b06/a6b57772-1431-be18-5184-ff059271b9e9?origin=1," 2021. [Online].

Available: https://api.mziq.com/mzfilemanager/v2/d/4270cd01-7524-4011-ae86-d125baa81b06/a6b57772-1431-be18-5184-ff059271b9e9?origin=1. [Accessed 18 04 2022].

[33] Click Petróleo e Gás, "https://clickpetroleoegas.com.br/pa-eolica-gigante-de-80-metros-fabricada-pela-aeris-energy-para-a-nordex-uma-das-maiores-fabricantes-de-turbinas-eolicas-do-mundo-embarca-no-porto-do-pecem-rumo-a-europa/," 2021. [Online]. Available: https://clickpetroleoegas.com.br/pa-eolica-gigante-de-80-metros-fabricada-pela-aeris-energy-para-a-nordex-uma-das-maiores-fabricantes-de-turbinas-eolicas-do-mundo-embarca-no-porto-do-pecem-rumo-a-europa/. [Accessed 18 04 2018].

[34] Canal Energia, "LM Wind Power Amplia Fábrica de pás Para Aerogeradores em Suape," 2018. [Online]. Available: https://www.canalenergia.com.br/noticias/53080772/lm-wind-power-amplia-fabrica-de-pas-para-aerogeradores-em-suape. [Accessed 18 04 2022].

[35] Reuters, "https://www.moneytimes.com.br/vestas-fecha-acordo-com-lm-wind-power-para-producao-de-pas-eolicas-em-pernambuco/," 2022. [Online]. Available: https://www.moneytimes.com.br/vestas-fecha-acordo-com-lm-wind-power-para-producao-de-pas-eolicas-em-pernambuco/. [Accessed 18 04 2022].

[36] WindPower, "https://www.windpowermonthly.com/article/1732146/chinese-engineering-firm-sinoma-plans-wind-blade-factory-brazil," 2021. [Online]. Available: https://www.windpowermonthly.com/article/1732146/chinese-engineering-firm-sinoma-plans-wind-blade-factory-brazil. [Accessed 18 04 2022].

[37] Torres Eolicas do Nordeste S/A, TEN, "About Us," 2019. [Online]. Available: https://ten.ind.br/. [Accessed 18 04 2022].

[38] GRI Renewable Industries, "GRI Towers Brazil," [Online]. Available: https://www.gri.com.es/en/localizacion/gri-towers-brazil/.

[39] Offshore Wind Biz, "GRI Renewable Industries to Build Offshore Wind Turbine Tower Factory in Hull," [Online]. Available: https://www.offshorewind.biz/2021/08/09/gri-renewable-industries-to-build-offshore-wind-turbine-tower-factory-in-hull/#:~:text=GRI%20Renewable%20Industries%20plans%20to,UK%2C%20the%20tower%20manufacturer%20said.. [Accessed 20 07 2022].

[40] Companhia Siderúrgica do Pecém, CSPecem, "Home Page," 2022. [Online]. Available: https://www.cspecem.com/pt-br/. [Accessed 18 04 2022].

[41] Grupo Aço Cearense, "https://www.grupoacocearense.com.br/produtos/," [Online]. Available: https://www.grupoacocearense.com.br/produtos/. [Accessed 18 04 2022].

[42] Oceaneering, "https://www.oceaneering.com/locations/," 2022. [Online]. Available: https://www.oceaneering.com/locations/. [Accessed 18 04 2022].

[43] MFX, "https://www.mfx.com.br/us/," 2016. [Online]. Available: https://www.mfx.com.br/us/. [Accessed 18 04 2022].

[44] GCube Insurance, "Unchartered Waters," 2021. [Online]. Available: https://www.gcube-insurance.com/insights/reports/. [Accessed 20 07 2022].

[45] Offshore Engineer Ditigal, "Brazil OSV Update," 2019. [Online]. Available: https://www.oedigital.com/news/464213-brazil-osv-update. [Accessed 20 07 2022].

[46] Riviera Newsletters, "Brazilian-flagged Vessels Take (Temporary) Lead Offshore," 2015. [Online]. Available: https://www.rivieramm.com/opinion/opinion/brazilian-flagged-vessels-take-temporary-lead-offshore-36334. [Accessed 23 05 202].

[47] World Marine Offshore, "Crew Transfer Vessels," [Online]. Available: https://wm-offshore.com/fleet/crew-transfer-vessels. [Accessed 20 07 2022].

[48] Esvagt, "Esvagt Vessel Fleet List," 2022. [Online]. Available: https://esvagt.com/services/fleet-list/.

[49] James Fischer Renewables, "Rampion Offshore Wind Farm," 2022. [Online]. Available: https://jamesfisherrenewables.com/updates/rampion-offshore-wind-farm.

[50] Offshore Energy, "Brazilian Vessel Owner Scores Hat-trick Award with Equinor," 06 04 2022. [Online]. Available: https://www.offshore-energy.biz/brazilian-vessel-owner-scores-hat-trick-award-with-equinor/. [Accessed 20 07 2022].

[51] REM, *https://www.remoffshore.no/fleet/,* 2022.

[52] Royal Wagenborg, *https://www.wagenborg.com/offshore-towage/sea-towage-pontoons-and-salvage,* 2022.

[53] Seaway7, *https://www.seaway7.com/vessels/albatross/,* 2022.

[54] renew.biz, "Union 'blasts' move to make Neart jackets in Asia," 28 Nov 2019. [Online]. Available: https://renews.biz/56710/union-blasts-move-to-make-neart-jackets-in-asia/.

[55] Secretaria Nacional de Portos, "Plano Mestre do Complexo Portuário de Itaqui," 2018.

[56] Ministério de Infraestrutura, "Plano Mestre do Complexo Portuário de Fortaleza e Pecém," 2020.

[57] Companhia das Docas do Ceará, "Plano de Desenvolvimento e Zoneamento – Porto de Fortaleza," 2021.

[58] M. d. S. C. Rodrigues, Pecem - uma trajetoria portuaria, Foraleza: Sebrae/Ce, 2007.

[59] A. Nogueira, "Porto do Pecém Nasceu Para ser via de Crescimento do Estado," Opovo, 02 March 2017. [Online]. Available: https://www.opovo.com.br/jornal/economia/2017/03/porto-do-pecem-nasceu-para-ser-via-de-crescimento-do-estado.html.

[60] Ministério de Infraestrutura, "Plano Mestre do Complexo Portuário de Natal," 2019.

[61] EEW Group, "EEW SPC Loads 116th Monopile for Hornsea Project 1," 10 2018. [Online]. Available: https://eew-group.com/about/news/detail/eew-spc-loads-116th-monopile-for-hornsea-project-1/. [Accessed 20 07 2022].

[62] BUSS Ports, "Herausforderung an die Hafenlogistik bei Offshore Windprojekten," 03 2017. [Online]. Available: https://offshoretage.de/wp-content/uploads/sites/5/2017/03/4OT15_F2_1620_Bussports.pdf.

[63] Wagenborg, "First Monopiles and Transition Pieces for Borkum Riffgrund II Delivered," 02 03 2018. [Online]. Available: https://www.wagenborg.com/news/first-monopiles-and-transition-pieces-for-borkum-riffgrund-ii-delivered. [Accessed 20 07 2022].

[64] Offshore Energy, "First Turbine Up at Yangjiang Nanpeng Island Offshore Wind Farm – Video," 11 07 2019. [Online]. Available: https://www.offshore-energy.biz/first-turbine-up-at-yangjiang-nanpeng-island-offshore-wind-farm-video/.

[65] Energy facts, "https://www.energyfacts.eu/seamade-offshore-wind-farm-completes-first-blade-installation/," 21 06 2020. [Online]. Available: https://www.energyfacts.eu/seamade-offshore-wind-farm-completes-first-blade-installation/.

[66] OffshoreWIND.biz, "Marine Designs Installs Pontoon for Ørsted in Barrow," 20 03 2018. [Online]. Available: https://www.offshorewind.biz/2018/03/20/marine-designs-installs-pontoon-for-orsted-in-barrow/.

[67] Fishermap.org, "Depth maps and Marine charts," 2022. [Online]. Available: https://usa.fishermap.org/depth-map/.

[68] Port of Esbjerg, "Business Renewables - Wind," [Online]. Available: https://portesbjerg.dk/en. [Accessed 28 04 2022].

[69] DEME Offshore, *Innovation: DP2 Offshore Installation Vessel,* https://www.deme-group.com/technologies/innovation.

[70] Cadeler, "Media Photos," [Online]. Available: https://www.cadeler.com/en/media/photos/. [Accessed 20 07 2022].

[71] NKT, "NKT Victoria - State-of-the-Art High Voltage Cable-Laying Vessel," [Online]. Available: https://www.nkt.com/products-solutions/high-voltage-cable-solutions/nkt-victoria?gclid=EAIaIQobChMI9-zxmNv1-AIV2eR3Ch1HnAqpEAAYASAAEgJS2vD_BwE. [Accessed 20 07 2022].

[72] Cadeler, "Our Wind Farm Installation Vessels," [Online]. Available: https://www.cadeler.com/en/vessels/. [Accessed 20 07 2022].

[73] Ramboll Group, *Photo Courtesy,* 2022.

Ramboll is an independent engineering, architecture and consultancy company founded 1945 in Denmark. Today, we have grown to over 16,000 experts globally in 35 countries and are owned by The Rambøll Fonden (The Ramboll Foundation) (98%) as well as our Ramboll Employees (2%). We support projects across our defined markets of Buildings, Transport, Architecture & Landscape, Water, Environment & Health, Management Consulting and Energy.

Offshore wind is a division of our Energy market and a key competence of Ramboll since 1989. Here, we are a world-leading engineering consultant, covering the full project lifecycle, as well as emerging market strategic advice and studies. Our 500+ world-class energy experts have been involved in more than 70% of all global offshore wind projects, and 50% of the world's offshore wind turbines rise from foundations engineered by Ramboll.

Ramboll's project development and advisory team supports developers, governments, and non-governmental organizations globally to accelerate the growth of offshore wind. Our market advisory services provide strategic assessment for reports like this one and continue down the value chain through project development, engineering, contracting and execution. We are always looking for bright minds to join us: ramboll.com/careers/offshore-wind.

We are proud to have supported this key investigation in continuing to develop Brazil's promising offshore wind potential.

GET IN TOUCH if you have questions or comments about this publication:

Lisa Keaton

Team Lead Project Development & Advisory
Offshore Wind, Germany
lisa.keaton@ramboll.com

Raya Peterson

Head of Project Development & Advisory
Global Wind
raya.peterson@ramboll.com

Bright ideas. Sustainable change.

RAMBOLL